35952 - R4 SC-Oconee
Intake

DUKE POWER COMPANY
STEAM PRODUCTION DEPARTMENT

OCONEE NUCLEAR STATION ENVIRONMENTAL SUMMARY REPORT 1971 – 1976

VOLUME 1

CITIZENSHIP
DUKE POWER
SERVICE

NOVEMBER 1977

TABLE OF CONTENTS

VOLUME 1	Page
Table of Contents	i
Executive Summary	iii
Chapter 1 Introduction	1
Chapter 2 Thermal Characteristics	19
Chapter 3 Water Chemistry	115
Chapter 4 Phytoplankton	193
Chapter 5 Periphyton	241
Chapter 6 Zooplankton	271
Chapter 7 Benthos	335
Chapter 8 Fisheries Research Lake Keowee	375
VOLUME 2	
Addendum A Compilation of Data Collected by Southeast Reservoir Investigations in Keowee Reservoir, 1972-1975 by SERI	406
Addendum A-1 Fish Populations in Keowee Reservoir, South Carolina Prior to Nuclear Power Generation, 1968-73 by SERI	411
Addendum A-2 Prediction of Fish Biomass, Harvest, and Prey-Predator Relations in Reservoirs by Robert M. Jenkins	467

TABLE OF CONTENTS (cont.)

	Page
Addendum A-3 Summary of Fish Population Data from Keowee Reservoir, 1972-1976 by SERI	480
Addendum A-4 Population Dynamics of Young-of-the-Year Fish in a Reservoir Receiving Heating Effluent by Richard Ruelle, William Lorenzen, and James Oliver	491
Addendum A-5 Life History Studies Reports and Assembled Data by SERI	514
Addendum A-6 Zooplankton and Benthos Studies in Keowee Reservoir, South Carolina by SERI	529
Addendum A-7 Creel Census in Reservoirs by South Carolina Wildlife and Marine Resources Department	578
Addendum A-8 Abstracts of Theses Resulting from U. S. Fish and Wildlife Service Funded Research on Keowee Reservoir, South Carolina by Donald Stephen Cherry Joanne Schultz Edwards Madelaine Ann Forsyth David Cannon Smith Jesse Alan Chappell Vicki Munger Ferguson	596

EXECUTIVE SUMMARY

1. The purpose of the studies described in this report was to detect and quantify the effects of the operation of Duke Power Company's Oconee Nuclear Station (ONS) on the thermal, chemical and biological characteristics of Lake Keowee, South Carolina. Water temperature, chemistry and fisheries studies were initiated before Lake Keowee reached full pond in 1971, while the phytoplankton, periphyton, zooplankton and benthos studies were begun either shortly before or after mid-1973 when Oconee Unit 1 was licensed to operate.

2. The three-unit Station operated at annual gross thermal capacity factors of 11, 28, 69 and 59% in the years 1973 through 1976, respectively. Duke Power Company expects future ONS capacity factors to be similar to that observed in 1975, or about 65 to 75%. The findings presented in this report should therefore be representative of the environmental impacts of ONS operation in future years.

3. Water temperature (Chapter 2) was the factor most directly affected by ONS operations. Oconee's intake skimmer wall allows the use of Lake Keowee's bottom waters for the source of the Station's cooling water. It has functioned effectively in preventing short-term recirculation of the discharged cooling water back to the intake and thus minimized Station discharge temperatures. The Station has never violated any of the AEC/NRC limits on cooling water discharge temperature, temperature rise (ΔT), or rate of decrease in discharge temperatures. Based on monitoring from April 1973 through December 1976, the maximum daily and monthly average Station discharge temperatures have been 34.4 C (93.9 F) and 32.7 C (91.0 F), respectively, both of which occurred in September 1975.

4. Lake Keowee's thermal characteristics (Chapter 2) have responded to Station operation much like Duke predicted:

   a) a distinct thermal "plume" from the Station discharge was evident from September through March of each year, resulting in localized vertical thermal gradients or stratification.

   b) a thermal plume was not apparent from April through August of each year;

   c) maximum summer temperatures in the lake's surface waters were only slightly different from pre-operational values;

   d) winter minimum temperatures, except in the immediate vicinity of the ONS discharge, were mainly a function of meteorological conditions each year; there was no significant "carryover" in the lake's heat content from one year to the next.

   e) Oconee's use of bottom waters resulted in a less distinct summer thermocline in the lake, and complete destratification of the top 20 or 25 m of the water column earlier (mid-September) than observed in pre-operational years, and;

f) maximum temperatures of the deep (20 to 30 m) waters of the lake in September of 1975 and 1976 were about ten degrees Celsius (18 deg. F) warmer than in the pre-operational period.

5. Dissolved oxygen (D.O) concentrations were monitored (Chapter 3) in the Station's cooling water and in Lakes Keowee and Hartwell. The most significant results are as follows:

   a) Summer and Fall D.O. concentrations in the Oconee discharge area and the Keowee Hydro tailrace (Lake Hartwell) were considerably higher than predicted in the 1972 Final Environmental Statement. Both 1) higher-than-expected D.O. concentrations in the ONS intake cove and 2) rapid mixing at the ONS discharge structure and at the Keowee Hydro intake and tailrace helped to minimize the areas affected by low surface D.O. concentrations;

   b) In weekly measurements of D.O. concentrations at the ONS intake and discharge structures, the lowest value observed from 1974 through 1976 was 3.4 mg/1;

   c) Operation of ONS caused surface D.O. concentrations of less than 5.0 mg/1 to occur over no more than 0.4% of Lake Keowee's area, and none of Lake Hartwell's area, and;

   d) Lake Keowee's total content of D.O. was higher in the late summer and fall of 1975 and 1976 than during this season of any previous year. This was attributed to both the natural "aging" of the reservoir and to the earlier "fall overturn" brought about by Oconee's use of bottom waters for cooling purposes. Operation of Jocassee Pumped Storage Station also might have had a positive effect on Lake Keowee's D.O. content.

6. The water chemistry of Lake Keowee (Chapter 3) can be summarized as follows:

   a) Lake Keowee has water of exceptional purity; it has low dissolved and suspended solids and nutrient concentrations, low hardness, and is mildly acidic.

   b) The mineral composition of the lake during the ONS operational period was very similar to that of the Keowee River prior to its impoundment.

   c) Based on the nitrogen/phosphorus ratios observed, phosphorus appeared to be the limiting nutrient for primary production in Lake Keowee. Total phosphorus, ammonia and nitrate-nitrite concentrations have steadily decreased since the reservoir was impounded, probably due to natural "aging".

   d) Seasonal fluctuations in the concentrations of ammonia, nitrate-nitrite, manganese and iron, among others, were less pronounced during the ONS operational period than they were previously. This was attributed to the induced mixing and resultant higher dissolved oxygen content of the lake caused by Oconee's use of bottom waters.

e) Heavy metal concentrations were generally below EPA recommended limits for the protection of aquatic life. Copper and cadmium sometimes exceeded these limits, but were not related to ONS operations.

7. The abundance of both Phytoplankton (Chapter 4) and Zooplankton (Chapter 6 and Addendum A-6) in the surface waters near the ONS discharge was always similar to abundance in the intake cove, but often substantially lower than in most other areas of Lake Keowee. The skimmer wall allows only deep waters, with seasonally lower concentrations of organisms than surface waters, to pass into the intake cove and thus through the Station's condenser cooling water (CCW) system. This design was found to minimize the number of phytoplankton and zooplankton subjected to entrainment (passage through the CCW system), and also resulted in relatively low discharge temperatures. The discharged water, being buoyant and having a sparse plankton community, had the effect of diluting the plankton community in the surface waters near the discharge. This effect is quantified in Chapters 4 and 6, and appears to have assumed a predictable pattern.

   Entrainment appeared to have very little effect on the viability of either phytoplankton or zooplankton. Primary productivity of entrained phytoplankton (Chapter 4) was not significantly altered (positively or negatively), and an average of only 2% of the total Crustacea entrained (Chapter 6) were immotile as a result of passage through the CCW system.

   The lake-wide species composition of the plankton communities appeared to change little from 1974 through 1976. In the phytoplankton, blue-green algae were rarely as abundant as diatoms, green algae and dinoflagellates. The zooplankton community was numerically dominated by rotifers and immature forms of cyclopoid and calanoid copepods. Both communities were sparse in abundance as compared to other piedmont reservoirs, as would be expected with Lake Keowee's low nutrient concentrations.

8. Periphyton (Chapter 5) was studied because of its value as an indicator of major spatial or temporal changes in water quality. Organic accumulation rates and algal densities showed similar spatial and seasonal trends. Seasonal trends throughout the lake appeared to be a function of both temperature and sunlight levels. With the exception of the sampling location closest to the ONS discharge, both accumulation rates and densities were lower at areas near the Station than at more distant areas of the lake. During both warm and cool seasons, the sampling location closest to the discharge had a more abundant periphyton community than most other locations. For the warm periods, this was attributed to the positive effects of currents at the discharge. For cool periods, the currents plus above-ambient water temperatures appeared to have positive effects. The periphyton species composition at this sampling location during warm periods was also different from that at other locations, apparently due to the currents and slightly lower pH values.

Based on periphyton species composition, densities and organic accumulation rates observed on artificial substrates, Lake Keowee can be classified as a circumneutral, oligotrophic lake. Although year to year and spatial differences were observed, the operation of ONS did not significantly alter the trophic status or water quality of Lake Keowee with respect to periphyton community.

9. The Benthos (Chapter 7 and Addendum A-6) of Lakes Keowee and Hartwell showed little, if any, detrimental effects of ONS operation. Bottom type and depth, rather than temperature, appeared to be the main factors influencing spatial distribution. Although there were considerable seasonal fluctuations, no substantial changes in taxonomic composition of the benthos were noted from year to year during the operational period.

   Chaoborous punctipennis was collected in much lower numbers from 1974 through 1976 than in 1973. This phenomenon may have been related to ONS operations, or to the introduction of threadfin shad to Lake Keowee in 1974, or to other indiscernable causes.

10. Studies of the fish community of Lake Keowee (Chapter 8 and Addendum A) were conducted by Duke Power Company and the Southeast Reservoir Investigations (SERI) of the U. S. Department of the Interior.

    The studies of impingement and entrainment indicated that the numbers of fish eggs, larvae and adults affected were too small to have a significant impact on the fishery of the reservoir. It was found that few fish eggs or larvae entered the intake canal (under the skimmer wall) and that there was little or no reproduction within the intake canal itself.

    Symptoms of Gas Bubble Disease have never been observed in any of the fishes collected from Lake Keowee. Observed concentrations of dissolved oxygen and nitrogen were apparently not high enough to cause this disease.

    The studies of species composition and general distribution of fish in Lake Keowee indicate no adverse effects resulted from the operation of ONS. While the abundance of many species has changed during the study period, changes caused by ONS could not be distinguished from those predicted to occur naturally. The rather steady decline of fish abundance from 1969 through 1976 is not unusual for a new reservoir, and the standing crop obtained in 1976 was very close to that predicted solely on the basis of Lake Keowee's dissolved solids concentration.

11. In conclusion, Lake Keowee continues to be inhabited by an aquatic community whose species composition is typical of a piedmont reservoir. The overall abundance of aquatic organisms is relatively low, as would be expected because of the reservoir's low nutrient concentrations. Some areas of the reservoir have been found to contain fewer planktonic organisms than other areas, and this is attributable, in part, to ONS operations. Most of the seasonal and year-to-year variability observed, however, is attributable to natural phenomena.

    It is felt that none of the changes in the aquatic community of Lake Keowee documented by this report constitutes a major adverse environmental impact of ONS operation, nor is any such impact likely to result from continued operation of the Station.

CHAPTER 1 INTRODUCTION

PURPOSE OF REPORT

This report summarizes the findings of Duke Power Company's aquatic ecology studies, which were conducted to determine the environmental impact of the operation of Oconee Nuclear Station (ONS). Data from these studies have been presented to the U. S. Nuclear Regulatory Commission, formerly the U.S. Atomic Energy Commission, in the form of Semi-Annual and Annual Reports (Duke Power Company 1973 a, b; 1974 a, b; 1975 a, b; 1976), in accordance with the Operating License for the Station (Duke Power Company 1973 c).

These studies were to be continued ".... for the period of time necessary to determine the environmental impact of the station," or until

> ".... it is established that no major adverse environmental impact has resulted or is likely to result from continued operation of the Oconee Nuclear Station and that the degree of impact that has occurred has stabilized and is not likely to change...." (Duke Power Company 1973 c).

This report focuses on the thermal, chemical and biological characteristics of Lake Keowee; it defines and quantifies notable changes in these aspects of the lake which have resulted from the operation of ONS. Comparisons are made: a) between years with varying amounts of operation by the Station, b) between areas of the lake, and c) between our findings and any effects of ONS on Lake Keowee which were predicted in the Final Environmental Statement (U. S. Atomic Energy Commission 1972).

DESCRIPTION OF STUDY AREA

OCONEE NUCLEAR STATION

Oconee Nuclear Station is a three-unit steam electric station with a net capability of 2580 MWe. It is located in Oconee County, South Carolina, about 40 km west of Greenville, S. C. The Station is part of Duke Power Company's Keowee-Toxaway Complex, which also includes Lake Keowee, Keowee Hydro Station, Lake Jocassee, and Jocassee Pumped Storage Station (Figure 1-1).

Lake Keowee, the source of cooling water for ONS, was formed from 1968 through 1971 by damming the Little and Keowee Rivers. A connecting canal (maximum depth 30.5 m) joins the two main arms of the lake. Flow into the lake comes primarily from these two rivers, but all flow out of the lake, except for negligible leakage through Little River dam, is through the Keowee Hydro Station. The Keowee Hydro intake structure (Figures 1-2 and 1-3) was was designed to allow only water from depths less than 10.7 m (35 ft) at full pond to pass downstream, thereby retaining the colder bottom waters in Lake Keowee.

Oconee Nuclear Station uses these bottom waters for its source of once-through condenser cooling water (CCW). The Station is located on an isthmus between the two main arms of the lake, with its CCW intake on the Little River Arm. A skimmer wall is located at the mouth of a narrow cove, about 1.5 km from the

ONS intake structure. The wall extends from 0.3 m above full pond surface elevation to a depth of approximately 20 m (Figures 1-4 and 1-5), thus allowing only water from 20 to 27 m deep (full pond) to pass into the intake cove and subsequently through the Station. The retention time of water in the intake cove (between the skimmer and the intake structure) is 6.4 hours at the maximum Station CCW flow rate of 128 m^3/sec and full pond (Table 1-1).

The Station intake structure consists of bar racks and fixed screens, two for each of the Station's twelve CCW pumps. Two pumps per Unit are normally operated in winter, four in summer, and three in spring and fall. With all three Units operating, Station CCW flows can range from about 86 to 128 m^3/sec.

As water passes through the condensers at 100% power level, it is heated by 8.9 to 13.3 C° (16 to 24 F°), at four and two pumps per Unit, respectively. Travel time through the condensers is about five to eight seconds, and from the intake structure to the discharge structure is about two to three and one-half minutes, depending on CCW flow rate.

Condenser cooling water returns to Lake Keowee through the Station's discharge structure which is located on the Keowee River Arm of the lake near the Keowee Dam. The discharge structure has openings from about 9 to 12 meters deep through which the CCW returns directly to Lake Keowee, with no discharge canal.

It is about three kilometers by lake from the discharge structure back to the skimmer wall. Since the condenser cooling water discharged from ONS is warm and buoyant, it flows at or near the surface of the lake. Thus, the skimmer wall prevents it from being "short-circuited" back to the intake structure. However, because the maximum CCW flow rate is about four times the average outflow from Lake Keowee, most of the CCW discharge water must eventually recirculate back through the Station. This process would theoretically take about 4.5 months, assuming full pond elevation, normal inflow-outflow rates, and maximum CCW flow rates. With the other factors as above, drawdowns of 3 m (10 ft) and 7.6 m (25 ft) would change the time required for recirculation to 3.5 and 2.5 months, respectively.

RESERVOIRS

Lake Keowee has a full pond elevation of 243.8 m (800 ft) msl. At full pond, it has a volume of approximately 1.18 x 10^9 m^3, an area of 74 km^2 (Table 1-2), a mean depth of 15.8 m, and a shoreline of about 480 km. Its mean retention time at an average river flow rate of 32.5 m^3/sec is 420 days. Outflow is through Keowee Hydro Station, and may vary from approximately 1.4 (leakage) to 560 m^3/sec. Monthly and annual average flows through Keowee Hydro are presented in Table 1-3. A summary of Lake Keowee water level fluctuations is shown in Table 1-4. Maximum allowable drawdown is 7.6 m (25 ft), while the maximum observed drawdown since the lake reached full pond in April, 1971 was 2.3 m (7.5 ft), in January 1977.

Lake Keowee also serves as the lower pond for the Jocasee Pumped Storage Station, which is located at the upper end of the Keowee River Arm of the lake. The Jocassee Station has reversible turbines with a maximum generating flow (into Lake Keowee) of about 820 m^3/sec and a maximum pumping flow (out of Lake Keowee) of about 775 m^3/sec. Net flow into Lake Keowee from Lake Jocassee is about 15.5 m^3/sec. Water is withdrawn at a depth of 13 to 20 m from Lake Jocassee and is discharged into Lake Keowee at a depth of about 13 to 20 m (Figure 1-6). Lake Jocassee has a volume of approximately 1.43 x 10^9 m^3, an area of 31 km^2, and a mean depth of 46 m at its full pond elevation of 338.3 m (1110 ft) msl.

Lake Hartwell, a reservoir impounded by the U. S. Army Corps of Engineers, is immediately downstream of Lake Keowee (Figure 1-8). There is no free-flowing stretch of river between Lakes Keowee and Hartwell. Hartwell Dam impounds an area of 247 km^2 at full pond elevation of 201 m msl.

OCONEE NUCLEAR STATION OPERATIONS

Operating capacity factors (thermal) for ONS are presented in Table 1-5. It was not until March, 1975, that the Station's monthly thermal output reached 50% of capacity, but from May, 1975 through January, 1976, it did not drop below 75% and averaged 82%. This high level of operation was sustainable for nine consecutive months only because Units 2 and 3 had just started operating and none of the three Units required refueling from March, 1975 to February, 1976. Each Unit normally requires a six to eight week refueling outage once each year. Since efforts are made to schedule only one Unit at a time "down" for refueling, there will probably be four to six months out of each year (after 1975) during which the Station will be operating at no more than two-thirds of capacity due to refuelings. Other scheduled and unscheduled outages added to this will likely result in annual capacity factors no greater than 80%, with 60 to 75% being the most probable range.

The study period for this report contained a wide cross section of ONS operating levels, and this presented an opportunity to study the effects of various levels of Station flow, ΔT, and discharge temperature on the chemistry and biology of Lake Keowee.

OTHER FACTORS

It must be remembered that ONS operation was not the only variable affecting Lake Keowee. The lake reached full pond in 1971, so that the study period represented the early successional years of the reservoirs's life during which time many natural physical, chemical and biological changes occurred. The phenomenon of reservoir "aging" has been studied extensively, but it is not possible to say exactly how or to what extent Lake Keowee's aging interacted with ONS operations in affecting the lake's chemical and biological characteristics.

Also during the study period, Lake Jocassee was filling (April, 1971 to December, 1973), and Jocassee Pumped Storage began operating (Units 1 and 2 in December, 1973; Units 3 and 4 in May, 1975). Filling Lake Jocassee had the effect of reducing the rate of inflow into Lake Keowee. This was indicated by the low outflow rates at Keowee Hydro Station for 1971 through 1973 (Table 1-3). At four unit operation, Jocassee Pumped Storage has the capability of causing flows into or out of Lake Keowee at a rate of six (6) times the maximum ONS CCW flow rate. While Jocassee's effects on the short and long-term elevation of Lake Keowee have been minimal (Table 1-4), its operation certainly had some effect on the currents present in Lake Keowee, which in turn could have affected thermal stratification patterns in the lake.

Several of the following chapters in this report cite these and other sources of "noise" which make it difficult to assign cause(s) to many of the spatial and temporal patterns observed in these studies. Other than some fisheries data (species lists and standing crop estimates), there is no pre-operational biological data on Lake Keowee presented in this report. Even if it were available, however, it would be unwise in this case to attribute all differences between pre-operational and operational observations as due to ONS. In addition, because of the chemical and hydrological differences between the two main arms of the lake, one must also use discretion when attempting to explain the cause of biological differences between areas of the lake.

In short, there are no true "control" periods of time or areas of the lake to use as yardsticks for measuring the effects of ONS operations. Some professional judgement must be used when attempting to conclude whether or not Lake Keowee (1) is a "healthy" ecosystem, and/or (2) will respond any differently to ONS in the future. We believe that the studies described in the following chapters of this report were of sufficient intensity and duration to meet the objectives of the Environmental Technical Specifications.

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Duke Power Company. 1973a. Oconee Nuclear Station. Semi Annual Report. Period Ending June 30, 1973.

____________________. 1973b. Oconee Nuclear Station. Semi Annual Report. Period Ending December 31, 1973.

____________________. 1973c. Appendix B to Operating Licensing Nos. DPR-38, DPR-47, and DPR-55, Duke Power Company. U. S. Atomic Energy Commission, Docket Nos. 50-269, 50-270, 50-287 (revised August 1, 1975, NRC), Washington, D. C.

____________________. 1974a. Oconee Nuclear Station. Semi Annual Report. Period Ending June 30, 1974.

____________________. 1974b. Oconee Nuclear Station. Semi Annual Report. Period Ending December 31, 1974.

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United States Atomic Energy Commission. 1972. Final Environmental Statement Oconee Nuclear Station Units 1, 2, and 3.

Table 1-1

Retention Times (Hours) of ONS Cooling Water from Skimmer Wall to Intake Structure

	At Elev. 243.8 m (800 ft)	At Elev. 242.3 m (795 ft)	At Elev. 240.8 m (790 ft)
4 pumps/Unit x3 Units (128 m^3/sec)	6.4	5.5	4.7
3 pumps/Unit x3 Units (112.5 m^3/sec)	7.3	6.3	5.4
2 pumps/Unit x3 Units (85.5 m^3/sec)	9.6	8.3	7.0

Table 1-2 Volume and Area Data for Lake Keowee

Water Surface Elevation-m(ft)	Surface Area sq. Km	Storage Volume 10^9 m^3
246.9 (810)	83.3	1.42
245.4 (805)	78.8	1.30
*243.8 (800)	74.4	1.18
242.3 (795)	70.1	1.07
240.8 (790)	65.8	0.97
239.3 (785)	61.2	0.87
237.7 (780)	56.6	0.78
237.1 (778)	55.1	0.75
**236.2 (775)	52.8	0.70
234.7 (770)	48.9	0.62
231.6 (760)	41.5	0.48
228.6 (750)	35.3	0.36
225.6 (740)	27.8	0.27
222.5 (730)	22.5	0.19
219.4 (720)	17.8	0.13
216.4 (710)	13.2	0.08
213.4 (700)	9.6	0.05
210.3 (690)	5.7	0.02
207.3 (680)	3.1	0.01
204.2 (670)	1.3	0.004
201.2 (660)	0.6	0.001
198.1 (650)	0.3	----

*Full Pond
**Maximum Allowable Drawdown (FPC)

Table 1-1

ion Times (Hours) of ONS Cooling Water
n Skimmer Wall to Intake Structure

	At Elev. 243.8 m (800 ft)	At Elev. 242.3 m (795 ft)	At Elev. 240.8 m (790 ft)
	6.4	5.5	4.7
:)	7.3	6.3	5.4
	9.6	8.3	7.0

YDRO STATION

1974	1975	1976
71.2	27.0	39.5
118.1	50.8	36.2
20.7	82.7	42.4
16.7	42.5	40.7
35.9	63.8	53.3
11.8	16.1	53.2
43.1	20.3	33.2
28.8	39.9	10.8
17.0	35.1	16.0
5.1	49.8	39.2
23.0	47.2	27.2
12.4	44.1	30.1
33.7	43.3	35.2
112.4	173.6	150.1

TABLE 1-4

Differences (in meters) Between Maximum and Minimum Water Levels in Lake Keowee by Month

	1971	1972	1973	1974	1975	1976	1977
January	--	0.5	0.6	0.7	0.4	0.3	1.9
February	--	0.8	0.4	0.8	0.4	0.2	0.7
March	--	0.4	0.5	0.5	0.4	0.4	1.3
April	--	0.4	0.4	0.7	0.2	0.8	0.6
May	--	0.2	0.7	0.7	0.5	0.9	0.5
June	--	0.4	1.4	0.4	0.6	0.4	0.7
July	--	0.4	0.5	0.9	0.7	0.5	1.1
August	--	0.4	0.5	1.2	1.1	0.8	1.3
September	0.4	0.6	0.6	0.4	1.1	0.9	
October	0.3	0.6	0.2	0.4	0.7	0.5	
November	0.3	0.8	0.2	0.4	0.4	1.2	
December	0.9	0.6	0.5	0.4	1.0	1.2	
Maximum Drawdown by Year (m below full pond)		1.9	1.6	1.9	1.3	1.4	2.3

TABLE 1-5

MONTHLY GROSS THERMAL CAPACITY FACTORS[1] (PERCENT) FOR OCONEE NUCLEAR STATION

MONTH	1973	1974	1975	1976	1977
January	0	13	37	91	90
February	0	28	22	49	77
March	0	29	57	47	72
April	0	26	61	27	92
May	4	5	76	33	76
June	9	43	78	64	46
July	15*	38	80	59	44
August	15	31	82	90	36
September	16	46**	76	77	
October	23	19	75	61	
November	23	31	92	52	
December	27	30***	92	55	
Annual Average	11	28	69	59	

*Unit 1 declared commercial on July 15, 1973.

**Unit 2 declared commercial on September 9, 1974.

***Unit 3 declared commercial on December 16, 1974.

[1] Based on three-unit capability for entire period:

$$\text{Gross Thermal Capacity Factor for ONS(\%)} = \frac{\text{Actual MWH(t) x 100}}{\text{7704 MW(t) x Hours in Period}}$$

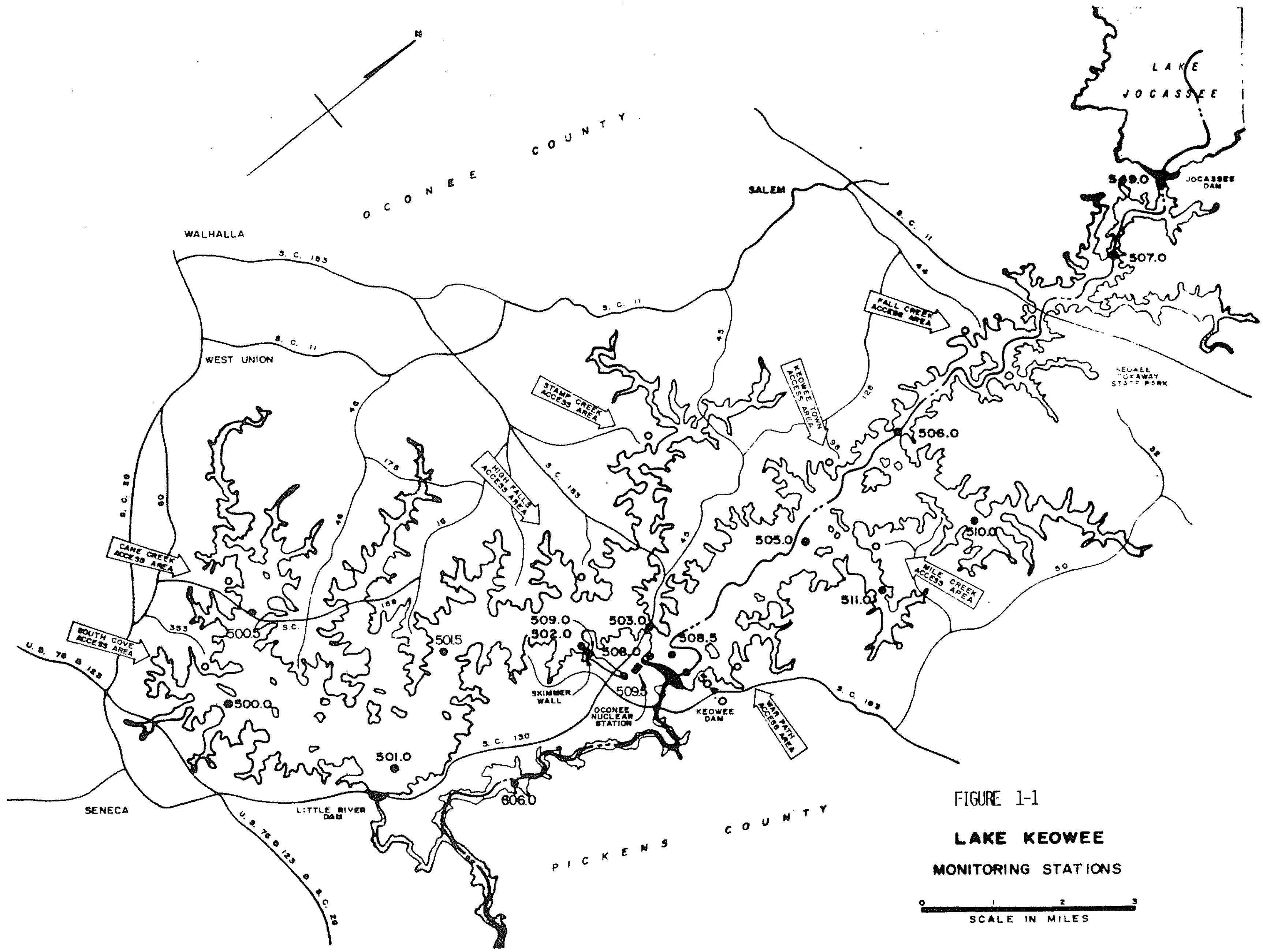

FIGURE 1-1

LAKE KEOWEE

MONITORING STATIONS

0 1 2 3
SCALE IN MILES

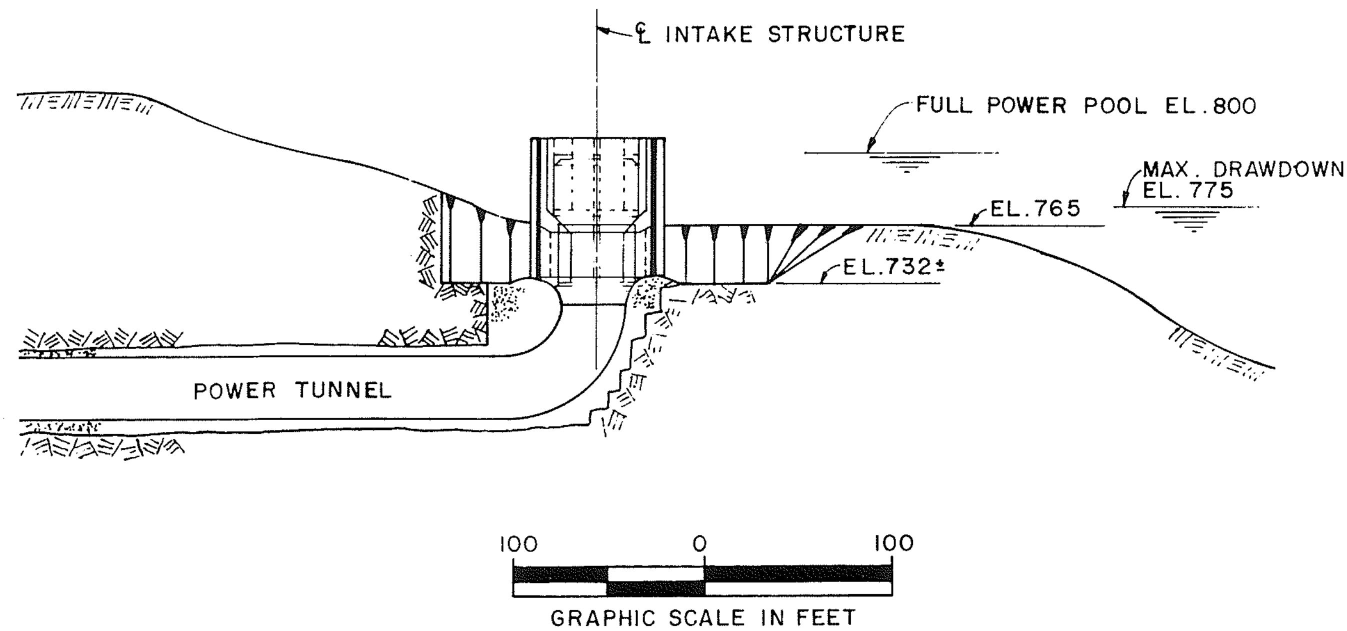

Figure 1-2
Sectional Profile of the Intake Structure, Power Tunnel and Submerge Weir at Keowee Hydro Station

OCONEE NUCLEAR STATION

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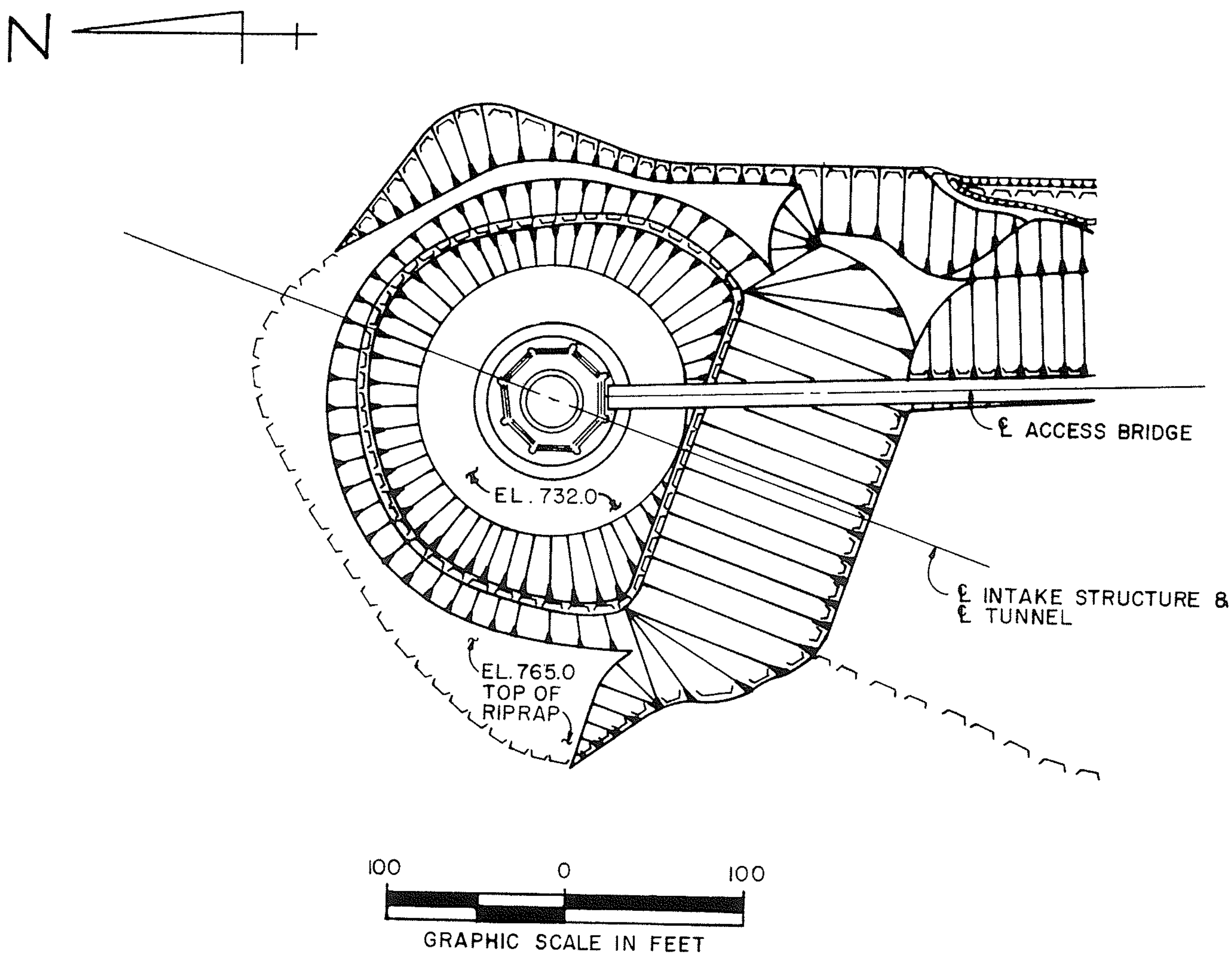


Figure 1-3
Plan View of the Intake Structure and Surrounding Submerged Weir at Keowee Hydro Station

OCONEE NUCLEAR STATION

DUKE POWER COMPANY

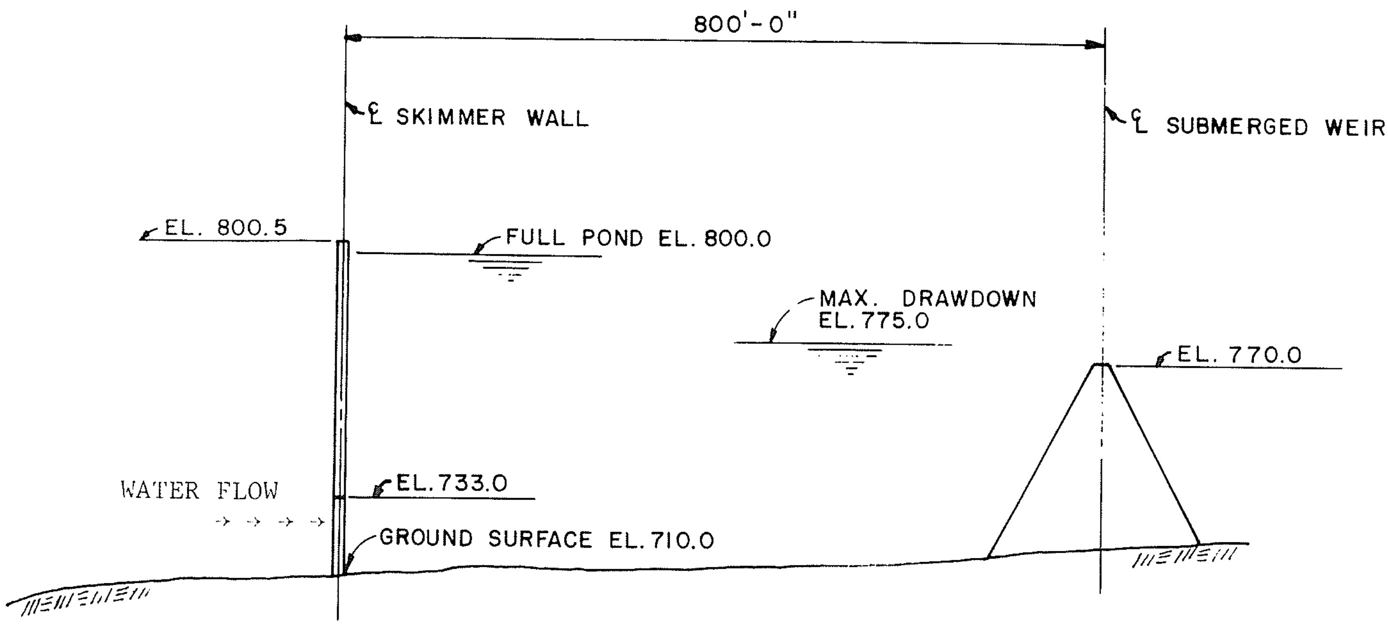


Figure 1-4

Schematic Profile of the Intake Skimmer Wall and Submerged Weir

OCONEE NUCLEAR STATION

DUKE POWER COMPANY

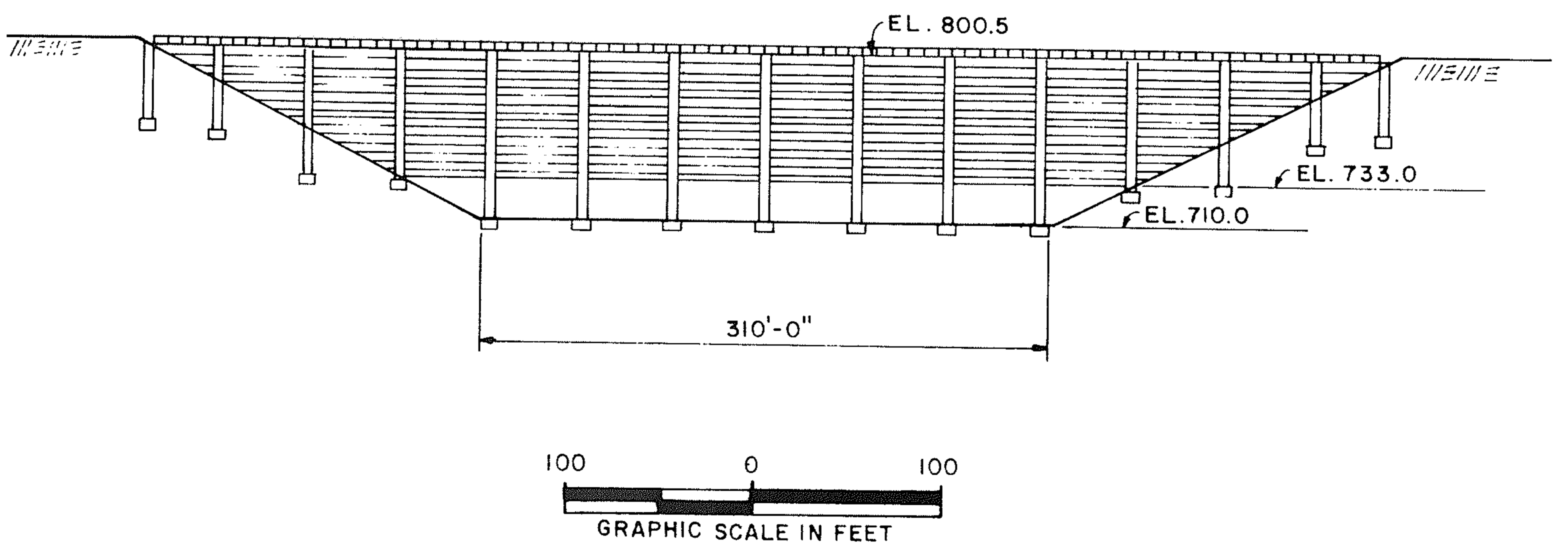


Figure 1-5
Downstream Elevation of the Intake Skimmer Wall at Oconee Nuclear Station

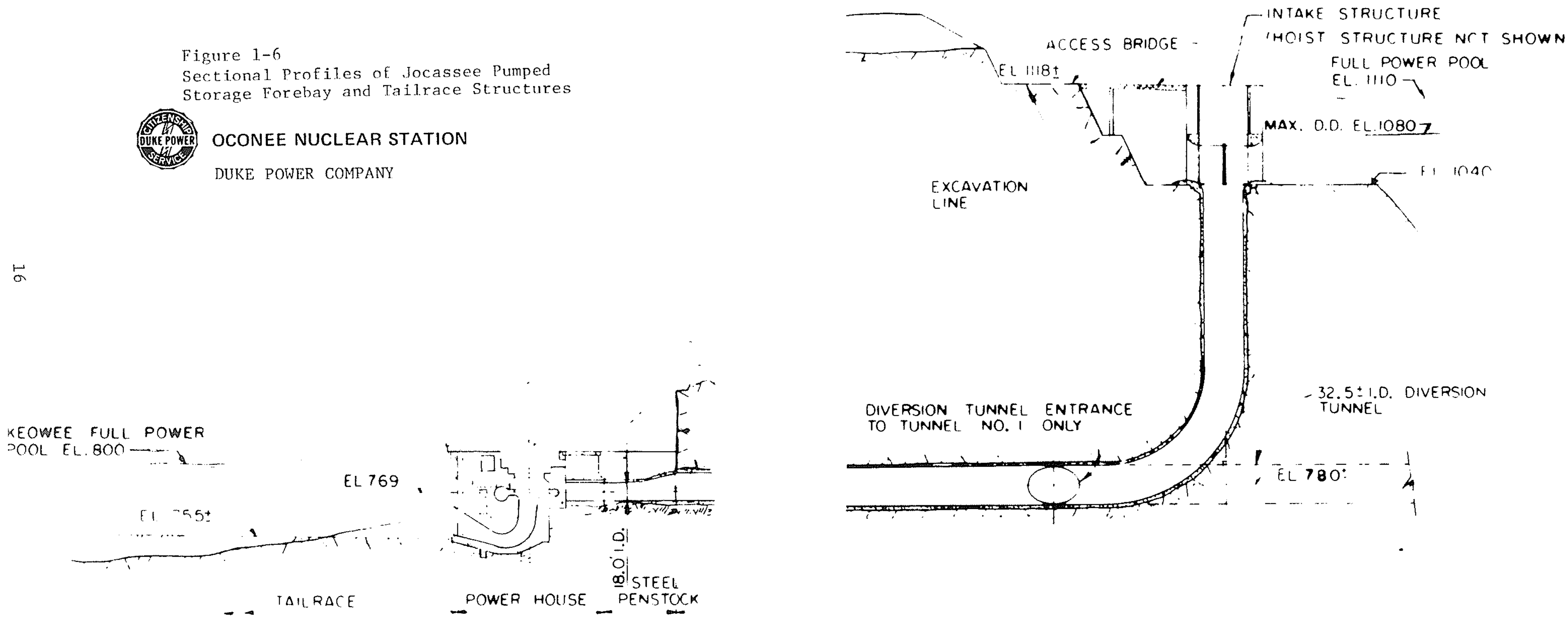
OCONEE NUCLEAR STATION

DUKE POWER COMPANY

Figure 1-6
Sectional Profiles of Jocassee Pumped Storage Forebay and Tailrace Structures

OCONEE NUCLEAR STATION

DUKE POWER COMPANY



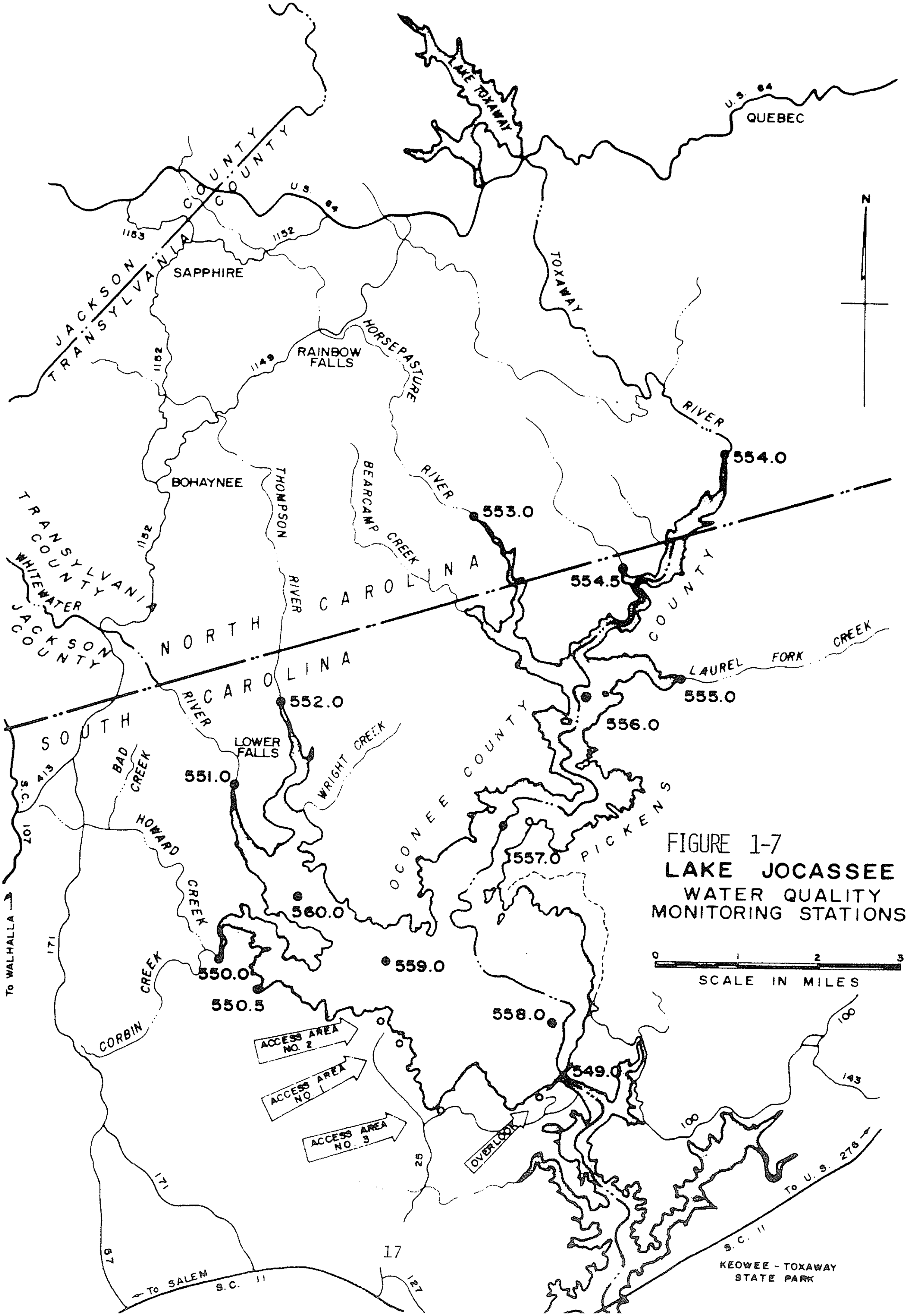


FIGURE 1-7
LAKE JOCASSEE
WATER QUALITY MONITORING STATIONS

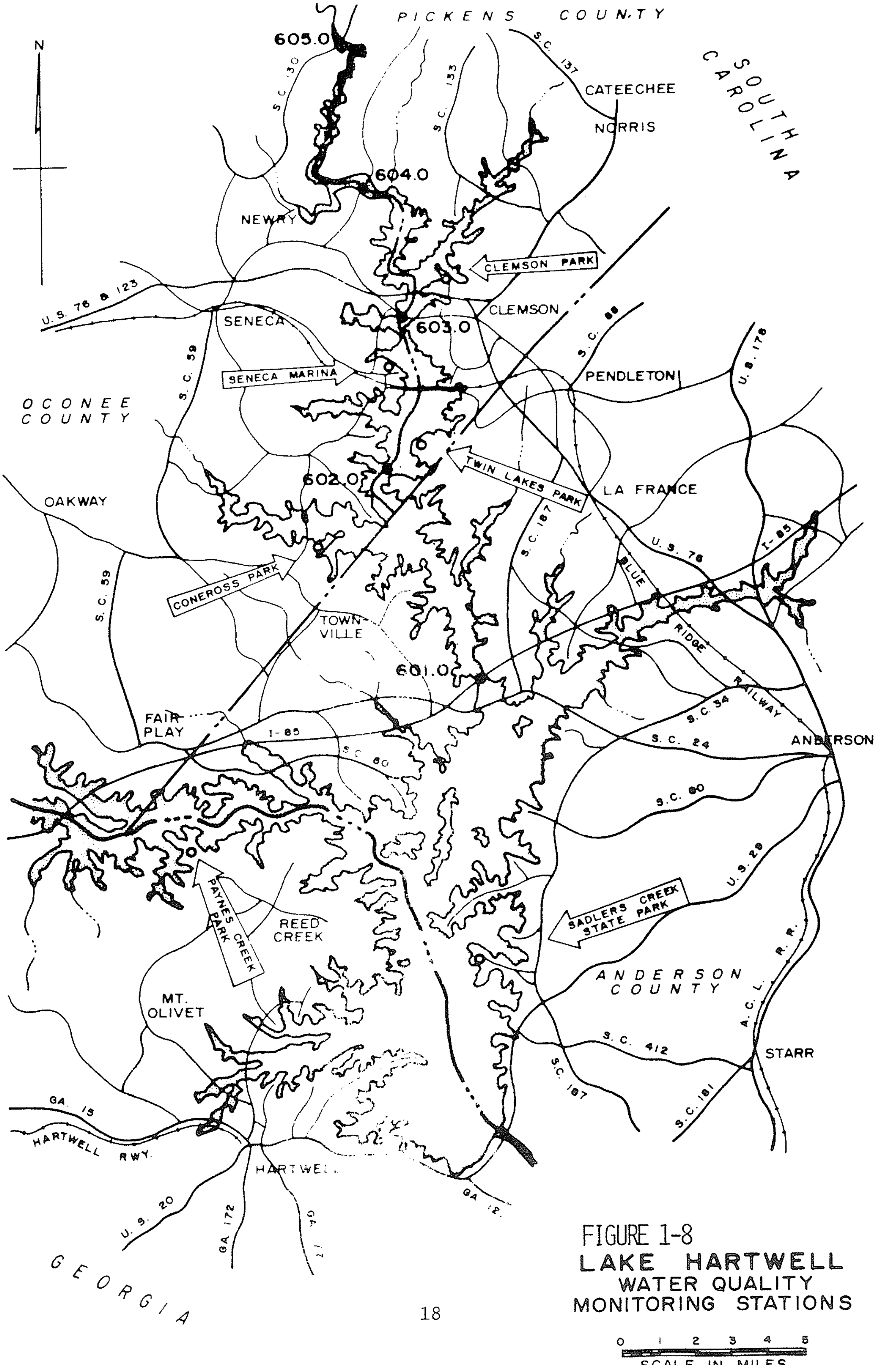


FIGURE 1-8
LAKE HARTWELL
WATER QUALITY
MONITORING STATIONS

CHAPTER 2 THERMAL CHARACTERISTICS

INTRODUCTION

The most direct effect the operation of ONS can have on Lake Keowee is upon the thermal characteristics of the lake waters. Operational effects of ONS on lake temperatures are of concern because of the large amounts of waste heat discharged (up to 1×10^{11} kcal per day), and the large volumes of Condenser Cooling Water (CCW) pumped through the station (up to 11×10^{6} cubic meters per day). Three Technical Specifications (Duke Power Company 1973a) for the operation of ONS concern temperature monitoring. These specifications (Specifications 1.1, 1.3.1, and 1.6), the design criteria, and the bases for them have been presented more extensively by the United States Atomic Energy Commission (1972) and Duke Power Company (1973a, b, c; 1974a, b; 1975a, b; and 1976). The major objective of the Technical Specifications was to determine what environmental impact had resulted or was likely to result from the continued operation of ONS.

Condenser Cooling Water thermal limits (Specification 1.1) were established to minimize the impact of thermal discharges on the aquatic biota of Lake Keowee. Limits were set on maximum discharge temperatures, temperature rise across the condensers, and the rate of decrease in discharge temperatures. A program was designed which monitored ONS compliance with established thermal limits, in addition to providing data which characterized the thermal aspects and flow rates of the CCW discharge.

The goal of the synoptic water quality program (Specification 1.3.1A), regarding temperature monitoring, was to characterize the thermal regimes of Lake Keowee both spatially and temporally. A continuous water temperature monitoring program (Specification 1.3.1B) was established to assess short-term water temperature variability proximate to ONS. This program provided data on the responses of lake temperatures to both ONS operations and meteorological changes.

Special plume studies (Specification 1.6) were implemented to characterize the CCW discharge plume and to verify the predictions of temperature gradients in the lake (United States Atomic Energy Commission, 1972).

METHODS AND MATERIALS

CONDENSER COOLING WATER THERMAL LIMITS (SPECIFICATION 1.1)

The inlet and outlet temperatures determined for this program were measured using resistance temperature devices (RTD's). A schematic of the basic CCW system is presented in Figure 2-1 and indicates the number and placement of RTD's in the system (per unit). Data collected from the CCW system were summarized by means of a computer program which calculated the unit mean pre- and post-condenser temperatures from appropriate RTD's. These values were then used to determine flow weighted station inlet and outlet temperatures and ΔT's. Condenser Cooling Water flow rates were measured by six pressure transmitters, two per unit. Station thermal limits and ONS compliance with those limits are summarized in Table 2-1.

SYNOPTIC WATER QUALITY PROGRAM (SPECIFICATION 1.3.1A)

Water temperatures were determined as part of the synoptic water quality program from January 1971 through December 1976. Temperatures were measured in situ monthly using a thermistor at nine or more locations on Lake Keowee (Figure 3-1) and at five locations on Lake Hartwell (Figure 3-2). Measurements were made at depths of 0.3, 1.5, 3.0, 5.0, 6.5, 8.0, 10.0 m, and every 2.5 m thereafter to 1 m above the bottom. Analytical methods, detection limits, and reporting units are presented in Chapter 3, Table 3-2. Data collected for this program have been presented previously (Duke Power Company, 1973b, c; 1974a, b; 1975a, b; and 1976).

Heat contents (heat above 0.0 C) were calculated from temperatures measured at Locations 500.0, 501.0, 502.0, 503.0, 504.0, 505.0, 506.0, and 507.0. Data from 0.3, 5, 10, 15, 20, 25, and 30 m were used to calculate average temperatures for the 0 to 10 m, 10 to 20 m, and 20 to 30 m water masses. These average temperatures were multiplied by appropriate volumes and conversion factors to obtain a heat content value (reference 0.0 C) for that stratum. A theoretical heat content value was calculated by multiplying the lake volume from 0 to 30 m by the average monthly equilibrium temperature. Both calculations took into account the lake elevation on the day of sampling.

CONTINUOUS WATER TEMPERATURE MONITORING (SPECIFICATION 1.3.1)

Water temperatures at Locations 502.0, 503.0, and 504.0 (Figure 3-2) were monitored every 15 minutes with an arrangement of thermistors attached to a floating buoy. The thermistors were hard wired to an instrument building on the shore which housed a Leeds and Northrup Speedomax strip chart recorder that recorded temperatures from selected depths (Table 2-2). Strip charts were collected weekly, and readings from 0600 and 1800 hours each day were stored on magnetic tape. The original charts were stored for future reference. The chart recorders were calibrated, according to manufacturer's recommendations, at the time of installation and at least every six months thereafter.

PLUME STUDIES (SPECIFICATION 1.6)

The most immediate effect of a CCW thermal plume on receiving waters is to cause increases in temperature especially in the upper water layers. The objectives of the ONS plume studies were to define the vertical and horizontal extent of the thermal plume in Lake Keowee.

Plume study design and scheduling were based upon the literature, (Bradey et al. 1969; Edinger and Borenstein 1973; Gray et al. 1969), Duke Power Company's past experience in plume mapping, predictions made by Duke Power Company of heat dissipation in Lake Keowee (United States Atomic Energy Commission, 1972), and ONS operations. The most extensive effects on Lake Keowee from the thermal discharge of ONS were expected; 1) during periods of maximum discharge temperatures (August, September, and October, 2) when maximum areas were covered by the CCW discharge plume (October through March), and 3) when minimum CCW dissolved oxygen concentrations were expected (August and September). Plume studies were scheduled during periods when these conditions were expected. Dissolved oxygen data collected during plume studies will be discussed in Chapter 3.

Temperature measurements collected during plume studies were obtained with an *in situ* sonde (Hydrolab Corporation, 1973). Temperatures were taken in a vertical profile (at intervals based on study objectives) and in most cases from the surface (0.3 m) to 1 m above the bottom. Temperatures were read to ± 0.1 C.

Prior to August 14, 1975, survey instruments were set up at shore control points and the locations of sampling boats were triangulated. The coordinates of the sampling boat were then located on a map. From August 14, 1975 on, sampling locations were located by visual alignment between reference points on the lake shore. Most of the reference points were located by survey crews by triangulation for placement on a map. The remainder were visually located on a map.

Sampling locations for plume studies conducted August 14, 1975 and after are shown in Figure 2-2. At least four studies were scheduled each year, and at least 30 locations were sampled during each study. As data were collected and inspected in the field, additional sampling effort was shifted to various areas of the lake to achieve more complete coverage of the thermal plume.

PREDICTIONS OF OCONEE NUCLEAR STATION PLUME CHARACTERISTICS

The Department of the Interior, Duke Power Company, and the Atomic Energy Commission conducted analyses to predict the temperature gradients that would be imposed on Lake Keowee from the operation of ONS (United States Atomic Energy Commission, 1972). The Duke Power Company analyses more closely approximated observed conditions, therefore, those analyses were used to compare predictions of temperature gradients in Lake Keowee to actual field data.

Predictions of temperature distributions in Lake Keowee were accomplished through the use of two one-dimensional "models". The first model, a computer model, predicted end of the month temperature profiles at Location 502.0. The second model, more appropriately called a physical comparison, was based on the method of Asbury and Frigo (1971) and temperature data collected at Marshall Steam Station on Lake Norman, North Carolina.

The one-dimensional computer model used to predict temperature profiles at Location 502.0 used a historical temperature profile for each month of the year and made adjustments to account for inflows to and outflows from the lake. The lake was treated as a deck of cards with each card representing a horizontal layer of water with a given temperature and volume. Inflows and outflows were inserted and removed at the proper depth based on temperature. The profile was then adjusted according to meteorological conditions with appropriate energy advected in and removed by the atmosphere during that month being accounted for. The final profile was a prediction of the temperatures at Location 502.0 for the last day of the month.

Average monthly ONS inlet temperatures were obtained from the temperatures predicted between 20 and 27 m (the skimmer wall openings) for Location 502.0. Adding an appropriate ΔT value based on expected ONS operations yielded the average monthly CCW outlet temperatures.

Original predictions were based on profile temperature data collected in Lake Hartwell and meteorological and hydrological data for 1965 to 1971 since enough data had not been collected from Lake Keowee to approximate its historical stratification pattern (United States Atomic Energy Commission, 1972). Predictions used for this report, however, were based on actual temperature, meteorological and hydrological data for 1975 and 1976.

To predict the distribution of surface temperatures on Lake Keowee the process of heat transfer from the surface of the lake to the atmosphere had to be taken into account as well as the dilution of the thermal effluent with receiving waters. At the time the predictions were being developed, the "state-of-the-art" for heat transfer between lake surface and the atmosphere was well advanced; however, little work had been done to account for mixing. Calculations accounting for mixing at that time failed to consider irregular shorelines, bottom geometry, and the transition of a heated effluent from jet to plume behavior.

Mixing was expected to play a significant role in the dissipation of heat from the CCW plume; therefore, a physical comparison was used. Marshall Steam Station on Lake Norman, North Carolina is analogous to ONS in many ways; 1) both Lakes Norman and Keowee are dendritic with long fetch oriented in the direction of prevailing winds, 2) both are large and deep enough to have a significant hypolimnetic volume, 3) the hypolimnions of both lakes are sources for CCW, and 4) both have hydroelectric stations which withdraw water from the top 10 m of the lake.

Asbury and Frigo (1971) used a physical comparison to normalize plume data so that data taken at one power station could be applied to other power stations. A similar analysis was done for ONS based on plume data collected at Marshall Steam Station. Using this method, expected ONS outlet temperatures, flow rates, and Lake Keowee ambient temperatures, surface temperature distributions for Lake Keowee were predicted prior to the operation of ONS (United States Atomic Energy Commission, 1972).

To validate this physical comparison actual ONS outlet temperatures, flow rates and Lake Keowee temperatures were used to calculate areas of Lake Keowee covered by the thermal plume for days in 1975 and 1976 when plume studies were conducted. Isotherms depicting affected plume areas were drawn from plume study data for these days, and areas encompassed by the isotherms were measured with a planimeter. The predicted plume areas were then compared to the observed areas.

RESULTS AND DISCUSSION

LAKE KEOWEE THERMAL CLASSIFICATION

Lake Keowee has thermal characteristics which classify it as a warm monomictic lake having one circulation period during the year, beginning in the fall, and is thermally stratified during the summer. During the circulation period, the water mass is vertically mixed. This type of lake can also be termed holomictic (Hutchinson, 1957). Lake Keowee might also be classified as a subtropical lake as it exhibits thermal stratification, a period of total circulation preceded by the fall overturn, and surface temperatures above 4 C. During the pre-operational study period thermal stratification in Lake Keowee began in April or May and continued until the beginning of the fall overturn in September or October (Figures 2-3 to 2-26). The highest surface temperatures typically occurred in July and August and ranged from approximately 27 to 29 C. During the periods from November through February the lake was isothermal or nearly so.

METEOROLOGICAL INFLUENCES ON WATER TEMPERATURES

Meteorological influences on lake water temperatures are primarily responsible for a lake's thermal characteristics. Additional influences on lake water temperatures are superimposed on natural temperature fluctuations. As air temperatures begin to increase during the spring an increase in surface water temperatures is initiated. As surface waters continue to warm a density gradient is established which inhibits vertical circulation of the lake waters. This phenomenon is depicted in Figure 2-27. The combined action of diffusion, wind-induced shearing, and internal seiches gradually heated the deeper waters despite the density barriers established (Edinger et al., 1974). In the fall, as surface temperatures decrease, density gradients are reduced to the point where wind induced mixing can circulate the entire water mass. It is this series of meteorological events that primarily govern Lake Keowee's thermal characteristics. The programs undertaken to monitor Lake Keowee temperatures have enabled conclusions to be drawn regarding the effects of ONS operations on the lake's naturally occurring thermal regimes.

OCONEE NUCLEAR STATION OPERATIONS

Oconee Nuclear Station utilizes a skimmer wall which allows waters from near the bottom of the lake (20 to 27 m deep at full pond) to be used for CCW. The withdrawal of water from the bottom of the lake and the thermal stratification which takes place in the summer results in the depletion of the lake's colder bottom waters and subsequently increasingly warmer inlet temperatures until thermal stratification begins to decrease in the early fall (Figure 2-28).

Station thermal limits and ONS compliance with those limits are summarized in Table 2-1. Operation of ONS through 1976 did not result in any violations of the limits. Daily and monthly average ONS CCW flow rates for the years 1973 through 1976 are presented in Figure 2-29 to 2-31. The maximum mean monthly flow rate of 7510 m^3 per min occurred in August of 1975. Flow rates were generally greater in 1975 than during any other year (Table 2-3). During most of the summer and fall of 1975 all three units at ONS were operational.

Heat rejection rates are presented in Figures 2-32 and 2-33 and represent the thermal input to Lake Keowee from the operation of ONS. The years 1975 and 1976 are clearly the years during this study when maximum impacts of ONS on Lake Keowee temperatures resulting from discharged heat would be expected.

A comparison of the mean monthly ONS inlet temperatures for the years 1973 through 1976 (Figure 2-28) indicated that the maximum temperatures for each year occurred during September except in 1973 when the maximum occurred in October. Recorded inlet temperatures reflected the trends observed in temperatures in the lake from depths of 20 to 27 m. The date the maximum inlet temperature occurred was during the fall when bottom water temperatures reached their maximum (Figures 2-9 to 2-14). As expected, the maximum mean monthly outlet temperature for a given year occurred during the same month as the maximum mean monthly inlet temperature (Figure 2-34). The maximum daily average outlet temperature for each year was 28.6 C on October 24 and 30, 1973; 29.6 C on September 20, 1974; 34.4 C on September 18, 1975; and 33.4 C on September 28, 1976 (Table 2-3).

In 1975, the annual gross thermal capacity factor for ONS was 69%, and in 1976 it was 59% (Table 1-5). It is unlikely that ONS capacity factors in the summer and fall months of future years will be significantly higher than those observed in 1975. Lake Keowee would, however, be more susceptible to thermal impacts from ONS operation if severe meteorological and drawdown conditions (such as those postulated in the Final Environmental Statement {United States Atomic Energy Commission 1972}) were to occur.

CONDENSER COOLING WATER THERMAL PLUME CHARACTERISTICS

Between August 1973 and December 1976, twenty plume studies were conducted on Lake Keowee to characterize the ONS CCW discharge plume. Data from these studies have been presented (Duke Power Company, 1973b, c; 1974a, b; 1975a, b; and 1976).

The greatest temperature influences on Lake Keowee due to the operation of ONS were expected to occur when ONS was operating at or near full capacity. Plume studies conducted in 1975 and 1976 are discussed below since these were the years when ONS operated with the greatest capacity factors. Data for 1973 and 1974 plume studies serve as supplementary data and sufficient interpretations have been presented (Duke Power Company 1973b, c; and 1974 a, b).

Vertical and Horizontal Distribution of the Plume

Surface temperature isopleths were constructed from data collected in 1975 and 1976 (Figures 2-35 to 2-45). The average surface temperature of locations 9 km from the ONS discharge in the Keowee River arm was used as a reference temperature. These locations were chosen as a reference since they were less influenced by the ONS discharge than most locations sampled in that arm (Figure 2-2).

As expected the extent of the ONS thermal plume was greater in the Keowee River arm of Lake Keowee than in the Little River arm (United States Atomic Energy Commission, 1972). Surface isopleths (Figures 2-35 to 2-45) indicated that the plume affected the same general portions of the lake, but to various extents, during the 1975 and 1976 studies. Warmer temperatures were recorded most often on the west side of the discharge cove and on the east side of the Keowee River arm. Temperature variability in the Little River arm of Lake Keowee resulting from the CCW discharge was small indicating that thermal plume travel through the connecting canal was minimal.

Since ONS discharges CCW into Lake Keowee at a depth of approximately 10 m, mixing was expected to result in rapid dilution of the discharge plume causing it to be less buoyant than if it were discharged on the lake surface (Duke Power Company 1973b). As a result, the ONS CCW discharge was expected to cause temperature increases deeper than a surface CCW discharge. Centerline decay plots were constructed for depths of 0.3, 5, and 10 m for locations sampled in the Keowee River arm during plume studies conducted in 1975 and 1976 (Figures 2-46 to 2-51). The data used for the centerline decay plots were the locus of maximum temperatures for that particular depth and transect (Tokar et al., 1975). The data were then normalized to the reference temperature (the average surface temperature of locations 9 km from the ONS discharge in the Keowee River arm).

Surface (0.3 m) centerline decay plots (Figures 2-46 and 2-47) indicated that temperature gradients from 3 to 9 C° existed between the ONS discharge and 1 km into the Keowee River arm during studies conducted in 1975 and 1976. Between 1 and 9 km greatly diminished temperature gradients were recorded. Between 5 and 9 km temperature differences less than 1 C° above the reference temperature were recorded.

Centerline decay plots for 5 m depths (Figures 2-48 and 2-49) showed large gradients within 1 km of the discharge; however, gradients were less than those observed for the surface centerline decay plots. Temperature differences of less than 1 C° above the reference temperature were recorded between 3 and 9 km for studies conducted in 1975 and 1976.

The centerline decay plots for 10 m depths for the 1975 and 1976 studies indicated large gradients existed within 0.5 km from the ONS discharge (Figures 2-50 and 2-51). Between 1 and 9 km the centerline decay showed little or no temperature gradients, indicating that the thermal plume had little effect on the temperature of the lake 10 m and below.

The 1975 and 1976 plume survey data indicated that the major temperature increases in the lake due to the ONS thermal plume occurred between the surface and 10 m depths and within 1 km of the discharge structure.

The ONS thermal plume did not extend far into Lake Hartwell. Monthly synoptic surface temperatures at Locations 504.0, 601.0, 602.0, 603.0, 604.0, and 605.0 were plotted versus distance from the ONS discharge structure (Figures 2-52 and 2-53). In general, surface temperatures at Location 504.0 (Keowee Hydro forebay) were warmer than the Hartwell locations; however, surface temperatures at Location 605.0 (Keowee Hydro tailrace) were approximately the same as surface temperatures at other Hartwell locations.

Plume Studies During Periods of Maximum Discharge Temperatures

The maximum CCW outlet temperatures at ONS typically occurred during August, September, and October (Figure 2-34). During these months the surface temperatures at the discharge were similar to those throughout the lake. This was due to the use of deep water for CCW and the rapid mixing at the CCW discharge.

In 1975, the maximum temperature recorded at the discharge structure during plume studies was 32.8 C recorded on August 14, 1975. In 1976, the maximum temperature at the discharge structure was 31.9 C recorded on September 15, 1976. The difference between surface temperatures at the ONS discharge and 9 km from the discharge was 1.9 C° on August 14, 1975 and 2.6 C° on September 15, 1976. Similar small temperature differences occurred for all plume studies conducted in August, September, and October.

Plume Studies During Periods of Maximum Thermal Plume Area

During the studies conducted to establish maximum CCW plume areas, November and December typically were the months when the plume was observed to cover the largest area. Large areas were also observed for February and March plume studies.

The largest recorded area covered by the plume during the 1975 and 1976 studies occurred on November 19, 1975. On that day, surface temperatures were 1.0 C° or less above the reference temperature (20.8 C) at a distance in the Keowee River arm 7 km from the ONS discharge (Figure 2-39). Surface temperatures of 1.0 C° or more above the reference temperature were recorded over approximately 18.1 km^2 (24.5%) of the total surface area of Lake Keowee.

The largest area covered by the plume during studies in 1976 was observed on September 15. On that day, surface temperatures in the Keowee River arm were 1.0 C° or less above reference at a distance 6 km from the ONS discharge (Figure 2-42). Surface temperatures 1.0 C° or more above the reference temperature (26.6 C) were recorded over approximately 10.6 km^2 (14.3%) of the total surface area of Lake Keowee. The largest plume area during the 1976 plume studies occurred in September probably because ONS operated at a much greater capacity during July through September than during October through December (Figure 2-33), the months when large plume areas would be expected. All other 1975 and 1976 September plume study data yielded smaller plume areas.

VALIDATION OF TEMPERATURE PREDICTIONS

Temperature Profile Predictions for Location 502.0

Comparisons of observed temperatures at Location 502.0 with temperatures predicted by the computer model (United States Atomic Energy Commission, 1972) using actual meteorological, hydrological and ONS operating data for 1975 and 1976 indicated that the model was able to give a reasonable prediction of observed conditions.

Predicted temperature profiles at Location 502.0 and observed temperatures (from the continuous water temperature monitoring program) on the last day of the month are shown in Figures 2-54 and 2-55. Typically the observed temperatures tended to be higher than the predicted temperatures. This was especially true in the winter months. For the 1975 data, the observed temperatures averaged 1.9 C° higher than the predicted temperatures, and for 1976, the observed temperatures averaged 1.7 C° higher than the predicted temperatures. Predicted inlet and outlet temperatures were extrapolations of temperature predictions for Location 502.0 between 20 and 27 m. The observed inlet and outlet temperatures, therefore, were also usually 1.0 to 2.0 C° higher than predictions (Figure 2-56 and 2-57).

Thermal Plume Area Predictions

Actual ONS outlet temperatures, flow rates and Lake Keowee temperatures for days in 1975 and 1976 when plume studies were conducted were used in the physical comparison (United States Atomic Energy Commission, 1972) to calculate plume areas. Predicted as well as observed plume areas are presented in Figures 2-35 to 2-45.

Examination of the values indicated that the observed plume areas were considerably less than those predicted from the physical comparison. While the physical comparison accounts for some mixing, the extent of mixing that occurred at ONS was not considered. The submerged discharge at ONS caused rapid mixing of the heated CCW with the receiving water. Because of the submerged ONS discharge, much more mixing probably occurred at ONS than at Marshall Steam Station, the station from which the physical comparison was based. Due to differences between ONS and Marshall Steam Station outlet geometries, and the extent of mixing occurring between the CCW discharge and receiving water, the physical comparison did not predict surface temperature distributions on Lake Keowee accurately. All of the predicted areas were much larger than the observed areas, hence the predictions were conservative.

Predictions of monthly average plume areas were made by Duke Power Company prior to the operation of ONS (United States Atomic Energy Commission, 1972). The predicted areas were based on maximum ONS operating conditions and historical meteorological conditions. These areas were larger than areas predicted using actual operating and meteorological conditions. During November, the month when the largest plume area was originally predicted, temperatures of 1.7 C° or more above reference were predicted over 22.4 km^2 (30.3%) of the total surface area of the lake. During the November 19, 1975 plume study (the study when the largest plume area was observed), surface temperatures of 1.5 C° or more above reference were observed over only 8.0 km^2 (10.9%) of the total surface area of the lake and surface temperatures of 2.0 C° or more above reference were observed over 2.0 km^2 (2.6%) of the surface area (Figure 2-39).

CONDENSER COOLING WATER LAKE-WIDE THERMAL EFFECTS

Lake Keowee is subjected to a number of factors which influence the lake's thermal regimes. The combined effects of Jocassee Pumped Storage operations, the remains of an unremoved coffer dam in the Little River arm, Keowee Hydro operations, ONS's deep water intake, and ONS operation including both CCW pumping and thermal discharges all contribute to alterations of expected thermal characteristics based on climatology of the Lake Keowee area alone. While there is certainly a direct relationship between ONS operations and Lake Keowee water temperatures, it should not be concluded that all changes in temperatures were due entirely to ONS.

The newly impounded reservoir (1971) increased in heat content (Figure 2-58) and water temperatures (Figures 2-3 to 2-26) before ONS began operations. Meteorological and hydrological considerations played the dominant roles in altering the lake's thermal regimes during 1971 through 1973 (ONS operated for 8 months in 1973 with a maximum monthly gross thermal capacity factor of only 27 percent). Summer equilibrium temperatures for 1973 averaged 2.8 C° higher than equilibrium temperatures for the summer of 1972 (Duke Power Company, 1974c). Lake Jocassee (Figure 3-3) was being filled at this time which effectively reduced the inflow of cool stream water into Lake Keowee. The increases in heat content from 1971 through 1973 made it impossible to establish a base line from which to quantify changes in heat content due to ONS operations, however 1975 provided data indicative of ONS operational extremes from which to assess ONS operational effects.

Lake Temperatures and Vertical Thermal Gradients

The effects of ONS operations on maximum summertime surface lake temperatures (Figures 2-3 to 2-26) have been negligible if not nonexistent. Maximum surface lake temperatures appear to be more a function of meteorological conditions than ONS operations. Except for Location 504.0 which is in the discharge area, Locations 501.0, 502.0, and 506.0 all yielded higher maximum surface temperatures in 1972 (pre-operational) than any other time during the period from 1971 through 1976.

While the operation of ONS has not had a pronounced effect upon the maximum summertime surface temperatures of Lake Keowee, operations have combined with the conditions mentioned earlier to alter the thermal vertical gradation compared to pre-operation. Vertical thermal gradients have decreased during thermally stratified periods (Figures 2-59 to 2-63) and increased during normally isothermal periods (Figures 2-61 to 2-64). This disruption of stratified and destratified temperature regimes was probably the most important direct effect of ONS operations. Many of the effects of ONS operations, both chemical and biological, summarized in this report will be related to this disruption of thermal gradation. This disruption of vertical thermal gradients primarily resulted from the fact that ONS artificially mixed Lake Keowee by utilizing a deep water CCW source.

Oconee Nuclear Station operations have reduced the thermal gradation normally existing in Lake Keowee by increasing the temperatures of the bottom waters through mixing (Figures 2-59 to 2-64). The shapes of the temperature versus depth curves for the study period revealed that during normally stratified periods there no longer existed a classical thermocline (Figures 2-59 and 2-60). Instead, the water column exhibited a gradual temperature gradient throughout its depth. Surface (0.3 m) to bottom ($\leq$ 30 m) temperature differences (Figures 2-61 to 2-63) showed that within pre-operational and operational periods, maximum differences were quite consistent at a given location although operational maximum temperature differences were lower than pre-operational differences. This suggests that in 1974, 1975, and 1976, mixing caused by ONS operations was relatively consistent in its impact on disruption of thermal gradation.

The bottom waters of Lake Keowee have exhibited larger temperature increases than surface waters (Figure 2-27). Theoretically the bottom waters should warm only gradually after thermal stratification commences. Mixing by ONS CCW pumping has resulted in bottom water temperatures exhibiting greater yearly increases than during pre-operational years. The maximum summertime average temperature for the 20 to 30 m water mass increased by about 10 C° from pre-operational to operational periods. There was a definite trend toward average temperatures of different water masses (0 to 10 m, 10 to 20 m, and 20 to 30 m) to approach the same temperature (Figure 2-27).

Short-Term Lake Temperature Responses

The continuous water temperature monitoring program yielded temperature data which provided insight into lake temperature responses to various influencing factors (Figures 2-65 to 2-68). Throughout the period 1973 to 1976 the variability of deeper water temperatures during thermally stratified periods increased due to the deterioration of thermal gradients. This variability was most often the result of wind induced seiches. Mixing of Lake Keowee waters resulted in decreased density barriers which permitted wind induced seiches and mixing to have a deeper effect on lake temperatures than during pre-operational periods.

Wind speed variations in May of 1973 (Figure 2-69) resulted in the temperature responses depicted in Figure 2-70. A seiche approximately 8 m deep resulted at Location 502.0. Wind speed variations in May of 1976 (Figure 2-71) resulted in a seiche approximately 12 m deep at Location 504.0 (Figure 2-72). Heat rejection rates for ONS during May of 1976 (Figure 2-73) were consistent and would not have produced the responses in temperature observed. In both of these situations, within several hours after wind speeds decreased, water temperatures returned to values similar to those recorded before increased wind speeds.

The largest daily increase in heat rejected by ONS (Figure 2-74) occurred between May, 31 and June 1, 1976 and resulted in temperature responses at Location 504.0 as depicted in Figure 2-75. Wind speed data for corresponding dates (Figure 2-76) indicated that no large variations in that parameter occurred. Increased temperatures occurred to depths of about 6 m and were apparently the result of ONS heat rejection.

While some of the temperature variability depicted in Figures 2-65 to 2-68 was due to ONS operations the majority was probably due to local meteorological disturbances. Reduced vertical thermal gradients resulting from ONS operations have resulted in wind influences affecting greater depths than would have been possible if stratification had not been altered.

Heat Content Considerations

Figure 2-58 represents the heat content of Lake Keowee waters from February 1971 through April 1977. The yearly maximum total heat content of Lake Keowee increased through 1975, then it decreased slightly in 1976. From 1971 through 1973 the lake was virtually unaffected by ONS operations, and still the lake increased in heat content. Disruption of thermal gradation is evidenced by the increased heat content of the 10 to 20 m and the 20 to 30 m water masses.

Meteorological conditions appear to be the major driving force determining the lake's heat content (Figure 2-77). The maximum heat content in 1975 was considerably higher than in previous years, however, 1971 through 1973 yielded yearly maximum increases with little or no input from ONS. In addition, 1975 equilibrium temperatures were persistently high for four months which would tend to raise the heat content relative to previous years. Heat content values for the summer of 1976 were lower than for 1975, indicating that the trend towards increasing heat content has ended.

Perhaps more important than the yearly maximum heat content is the ability of the lake to lose its "residual" heat in the winter to avoid a carryover of heat into the next warming cycle. Based on 1977 data, the lake nearly equaled its 1971 yearly minimum heat content. From 1971 to 1973 the yearly minimum heat content of the lake increased responding to natural conditions (only small amounts of heat were rejected by ONS during this period).

SUMMARY AND CONCLUSIONS

Operations of ONS from 1973 through 1976 did not result in any violations of the thermal limits established for the Station. While it is unlikely that ONS operating capacity factors in the summer and fall months of future years will be significantly higher than those observed in 1975, Lake Keowee would be more susceptible to thermal impacts from ONS operations if severe meteorological and drawdown conditions were to occur.

The ONS discharge plume affected the Keowee River arm of the lake more than the Little River arm. In general, the thermal plume was observed near the west bank of the discharge cove and along the east bank of the lake in the Keowee River arm. Temperature gradients from the discharge to 1 km from the discharge were quite pronounced at the surface, 5 m and 10 m depths. At the surface (0.3 m) and 5 m depths, the 1 C° isotherm (above reference) usually occurred between 1 km and 5 km from the discharge. At the 10 m depth, however, this isotherm rarely occurred at distances greater than 1 km from the discharge. Maximum CCW discharge temperatures typically occurred during August, September, and October. During these months, because of Oconee's use of deep water for CCW and the rapid mixing at the CCW discharge, the surface temperatures near the discharge structure were similar to those in other areas of the lake. The maximum discharge temperature recorded during 1975 and 1976 plume studies was 32.8 C recorded on August 14, 1975. During that study, the difference between surface temperatures at the ONS discharge and surface temperatures in the Keowee River arm 9 km from the discharge was only 1.9 C°. The CCW plume typically affected the largest areas from November to March. The largest plume area recorded during plume studies was on November 19, 1975, when surface temperatures of 1.0 C° or more above the reference temperature were recorded over approximately 18.1 km^2 (24.5%) of the total surface area of Lake Keowee.

Temperature predictions at Location 502.0 were found to be comparable to observed data. Comparisons of observed and predicted thermal plume areas indicated that observed values were always considerably less than predicted values. Hence, the predictions of plume areas were conservative. The physical comparisons used to predict areas covered by the thermal plume failed to account for the rapid mixing that occurred at ONS due to the submerged discharge.

The effect of the ONS thermal plume was to increase the spatial temperature gradation of Lake Keowee especially in the upper water layers. Plume study data collected from 1973 through 1976 has defined, with respect to depth and area, the portions of the lake affected most by the thermal plume and given indications of what to expect in the future. Future plume studies would only substantiate plume data collected between 1973 and 1976 and would be of little value.

Oconee Nuclear Station operations have not had an appreciable effect on maximum summertime surface lake temperatures. Deep water temperatures, however, have increased considerably due to ONS operation, but increases appear to have stabilized. Vertical thermal gradation in Lake Keowee has been altered by ONS operation, resulting in decreased temperature differentials during typically stratified periods and increased temperature differentials during destratified periods. This disruption of stratified and destratified temperature regimes is probably the most important direct effect ONS had on Lake Keowee waters. This disruption resulted from the fact that ONS mixed Lake Keowee by utilizing a deep water CCW source.

Analyses of short-term lake temperature responses indicated that deep water temperature variabilities have increased since ONS operations began. These variabilities were most often due to wind-induced seiches. Such variabilities were short-lived and resulted in no significant long term temperature changes.

RECOMMENDATIONS

Based on the findings of this report it is recommended that the following modifications be made to the Technical Specifications for the operation of ONS (Duke Power Company, 1973a):

1) Since ONS operations had little effect on Lake Hartwell temperatures, monitoring of Lake Hartwell (Specification 1.3.1A) should be limited to Location 605.0.

2) Since Lake Keowee temperatures display definable seasonal patterns, monitoring of Lake Keowee (Specification 1.3.1A) should be reduced to six times per year.

3) Since (a) lake temperature responses have been documented, (b) variabilities were short-lived and (c) most variability was the result of wind induced seiches rather than ONS operations, requirements for continuous monitoring of Lake Keowee temperatures (Specification 1.3.1B) should be omitted except for a location in the discharge area (504).

4) Since plume studies have defined, with respect to depth and area, the portions of Lake Keowee affected most by the thermal plume and given indications of what to expect in the future, requirements for monitoring the ONS thermal plume (Specification 1.6) should be terminated.

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Table 2-1

Summary of Oconee Nuclear Station Compliance with Station Thermal Limits*.

	1973**		1974		1975		1976	
	Temp.	Date of Occurrence	Temp.	Date of Occurrence	Temp.	Date of Occurrence	Temp.	Date of Occurrence
Maximum Discharge Temperature (C)								
Daily Average	28.6	10/24, 30	28.5	11/8	34.4	9/18	33.4	9/23 through 9/28
Hourly Average	28.6	10/24, 30	31.6	9/17	34.5	9/16	35.1	9/10
Maximum Inlet Temperature (C)								
Daily Average	19.3	10/30	22.9	9/26	26.0	9/12	25.0	9/12, 13
Hourly Average	19.3	10/30	23.1	9/26	26.4	9/12	25.1	9/12
Minimum Inlet Temperature (C)								
Daily Average	10.9	12/31	10.4	2/27, 28	9.9	2/14, 16, 18, 19	9.2	2/8
Hourly Average	10.9	12/31	10.1	2/27	8.9	2/15	9.1	2/8, 9
Maximum ΔT (C°)								
Daily Average								
Inlet Temperature 20 C	***		7.6	9/11	10.0	7/23, 24	9.3	8/9
Inlet Temperature 20 C	11.2	12/4	11.6	4/1	10.7	5/31	13.3	2/4, 5
Hourly Average								
Inlet Temperature 20 C	***		9.2	9/14	10.3	7/23	10.4	9/10
Inlet Temperature 20 C	12.7	11/19	11.9	4/1	11.3	1/15	13.7	1/29
Maximum Hourly Decrease in ΔT (C°)								
Winter	2.7	12/23	2.2	12/25	2.2	1/15	2.6	1/22
Spring, Summer, and Fall	4.9	7/23	4.9	7/5	1.8	4/16, 6/21	4.1	6/8

* Station Thermal Limits
(a) The discharge temperature shall not exceed 37.8 C for a time period of more than 2 hours
(b) The temperature rise across the condensers shall not exceed 15.6 C° when the inlet temperature is less than 20.0 C and 12.2 C° when the inlet temperature is greater than 20.0 C
(c) The discharge temperature shall not decrease more than 3.3 C° per hour during the winter and 5.6 C° per hour during the spring, summer, and fall.

** Period of July 1 through December 31.

*** The inlet temperature did not exceed 20.0 C during the period.

Table 2-2
Sample Depths for Continuous Water Temperature Monitoring
(Specification 1.3.1b)

Location No.	502.0	503.0	504.0	504.0	504.0
Dates Effective	1/1/73- 12/31/76	1/1/73- 12/31/76	5/10/73- 3/28/75	3/28/75 1/23/76	1/23/76 12/31/76
Depths (m)	0.3	0.3	0.3	0.3	0.3
	1.5	1.5	1.5	1.5	1.5
	3.0	3.0	3.0	3.0	3.0
	4.6	4.6	4.6	4.6	4.6
	6.1	6.1	6.1	6.1	6.1
	7.6	7.6	7.6	7.6	7.6
	9.1	9.1	9.1	9.1	9.1
	12.2	12.2	12.2	12.2	12.2
	15.2	15.2	15.2	15.2	18.3
	18.3	18.3	22.8	30.5	24.4
	27.4	30.5	30.5	36.6	BOTTOM
			BOTTOM		

Table 2-3

Summary of Oconee Nuclear Station Condenser Cooling Water Monitoring[1].

Date (Month/Year)	Flow (M^3/min)	Inlet Temp (C)	Discharge Temp (C)	Maximum Discharge Temp[2] (C)	ΔT (C°)	
7/73	1890.2	11.6	16.9	20.8	5.3	
8/73	1910.3	13.8	18.6	23.8	4.6	
9/73	2099.5	15.9	21.2	26.4	5.3	
10.73	2232.5	18.0	25.3	28.5	7.3	
11/73	2170.7	16.6	24.3	27.8	7.7	
12/73	3284.6	13.1	17.2	26.0	4.1	
1/74	3069.3	10.9	15.1	19.0	4.2	
2/74	3069.4	10.9	18.3	19.8	7.4	
3/74	2976.9	11.1	19.5	24.9	8.4	
4/74	2807.3	13.4	21.4	26.9	8.0	
5/74	2164.6	14.2	16.9	23.8	2.7	
6/74	4171.8	15.8	23.8	24.3	6.0	
7/74	5334.6	18.3	23.4	26.1	5.0	
8/74	4727.1	20.4	25.2	27.2	4.8	
9/74	5961.4	22.0	27.8	29.6	5.8	
10/74	4953.4	21.6	25.1	27.6	3.5	
11/74	4202.1	18.0	25.9	28.1	7.9	
12/74	5225.6	12.6	18.5	23.8	5.9	
1/75	4612.4	10.8	17.1	21.2	6.3	
2/75	3694.9	10.1	14.9	16.5	4.8	
3/75	5456.8	10.4	18.6	21.8	8.2	
4/75	5570.8	11.7	20.0	21.7	8.3	
5/75	6494.3	13.5	22.3	25.4	8.8	
6/75	6574.2	16.6	25.4	26.8	8.8	
7/75	7104.2	20.3	28.6	31.3	8.3	
8/75	7510.1	23.7	31.5	33.8	7.8	
9/75	7201.6	25.3	32.7	34.3	7.4	
10.75	6993.4	22.7	30.4	31.8	7.7	
11/75	7467.1	19.4	27.9	29.6	8.5	
12/75	6850.9	15.0	24.4	26.0	9.4	
1/76	6069.3	10.7	21.3	23.6	10.6	12.5
2/76	4440.2	9.5	16.8	22.6	7.3	11.4
3/76	4874.3	10.6	17.7	20.8	7.1	10.4
4/76	4272.1	12.3	17.4	19.3	5.1	11.4
5/76	3970.7	13.9	19.7	20.8	5.8	9.3
6/76	5197.6	16.1	25.4	26.3	9.3	8.4
7/76	5830.0	18.6	26.0	29.4	7.4	7.4
8/76	7248.3	22.2	30.7	32.9	8.5	5.0
9/76	6785.4	24.6	32.6	33.3	8.0	5.0
10.76	5637.8	22.0	29.8	33.0	7.8	3.8
11/76	5809.2	16.0	22.7	24.8	6.7	6.2
12/76	4914.8	11.8	20.2	21.8	8.4	7.9

[1] Monthly means of daily average values for the month.

[2] Maximum daily average discharge temperature for the month.

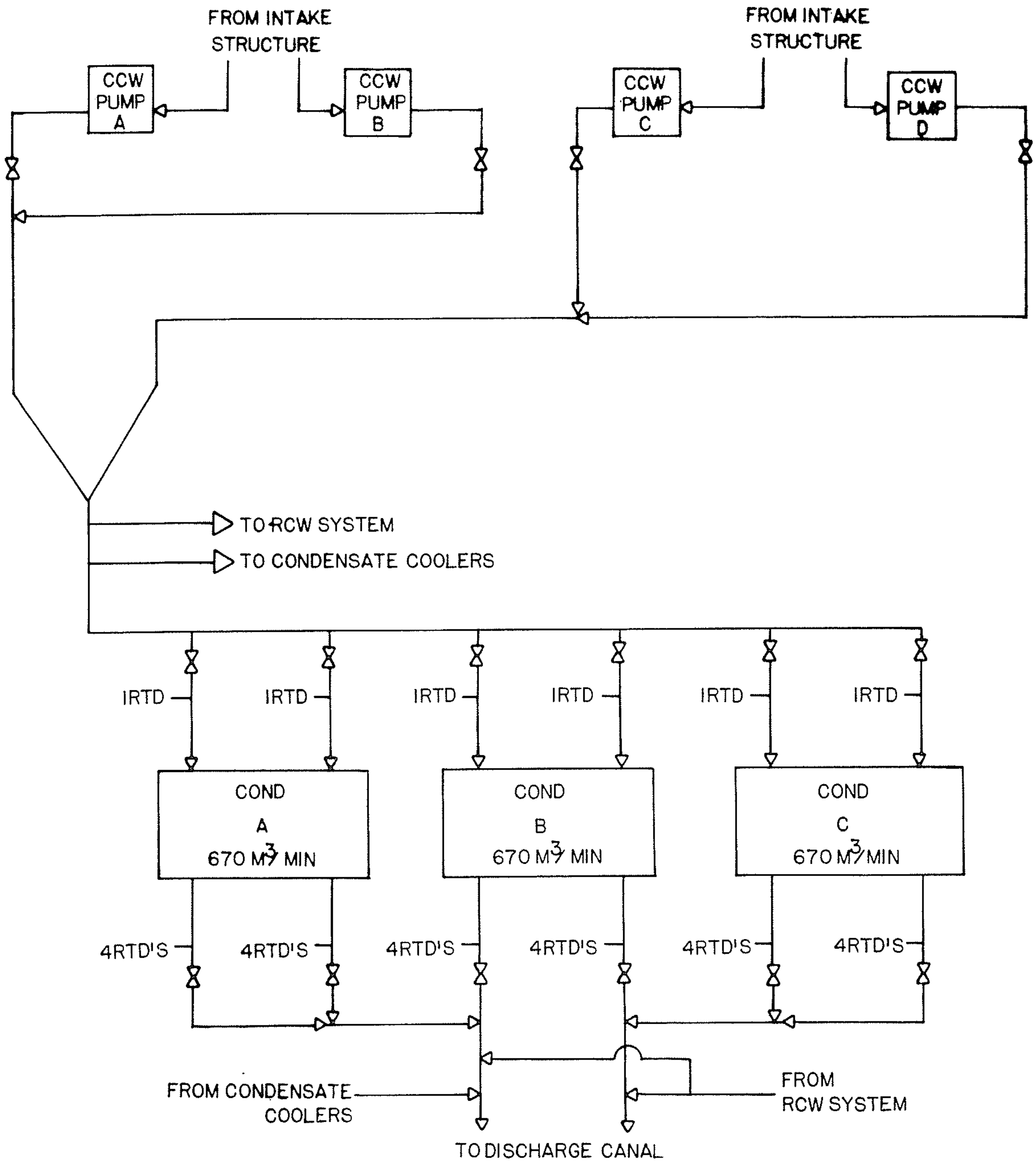
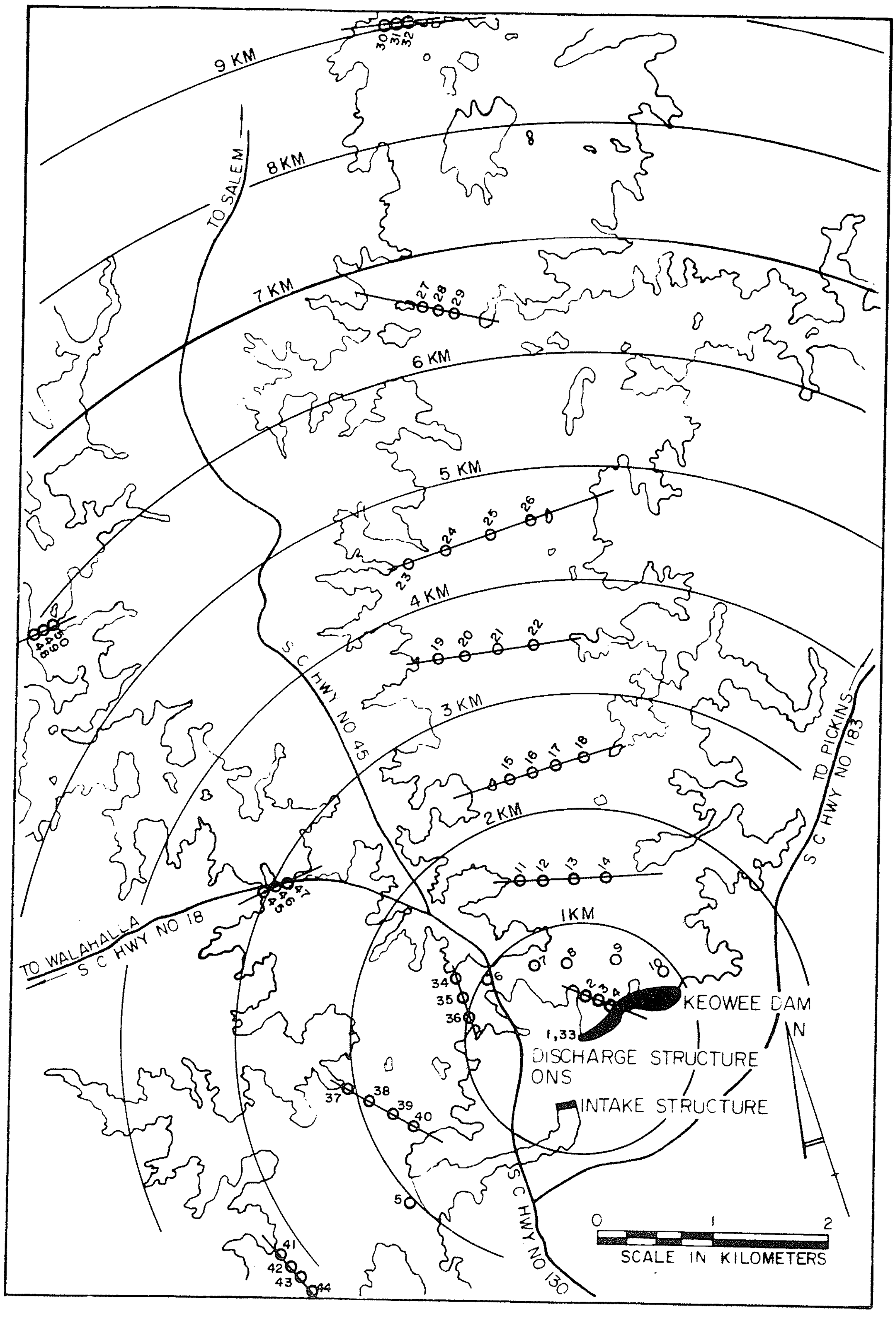


Figure: 2-1 Schematic of Oconee Nuclear Station Basic Condenser Cooling Water System - Unit 1 (ref: P.O. Drawing 113A, Rev. 2/22/71)



OCONEE NUCLEAR STATION
PLUME MAPPING STUDY
STATION LOCATIONS

FIGURE 2-2

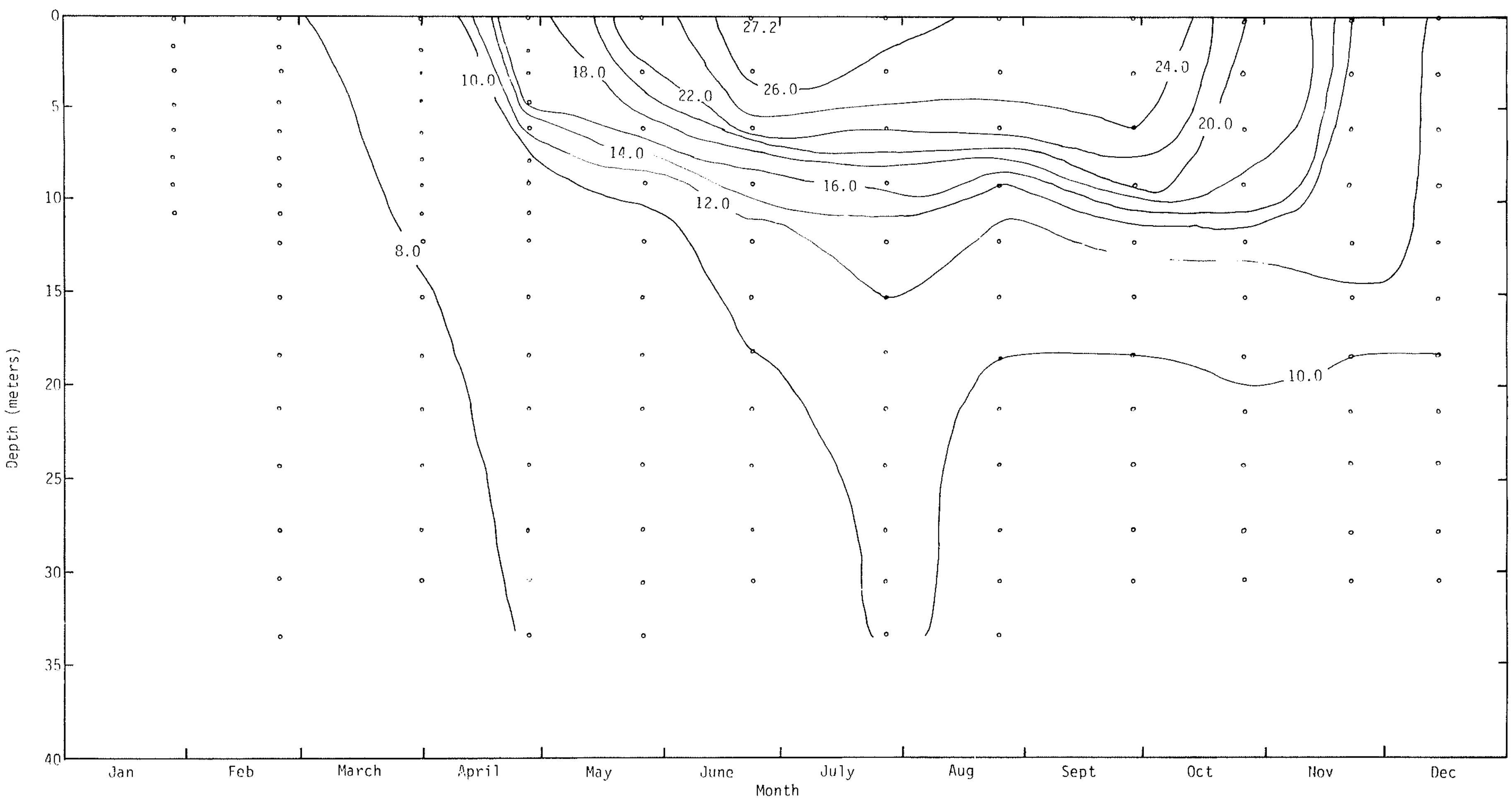


Figure 2 - 3 Temperature Isopleths (C) for Location 501.0 on Lake Keowee for 1971

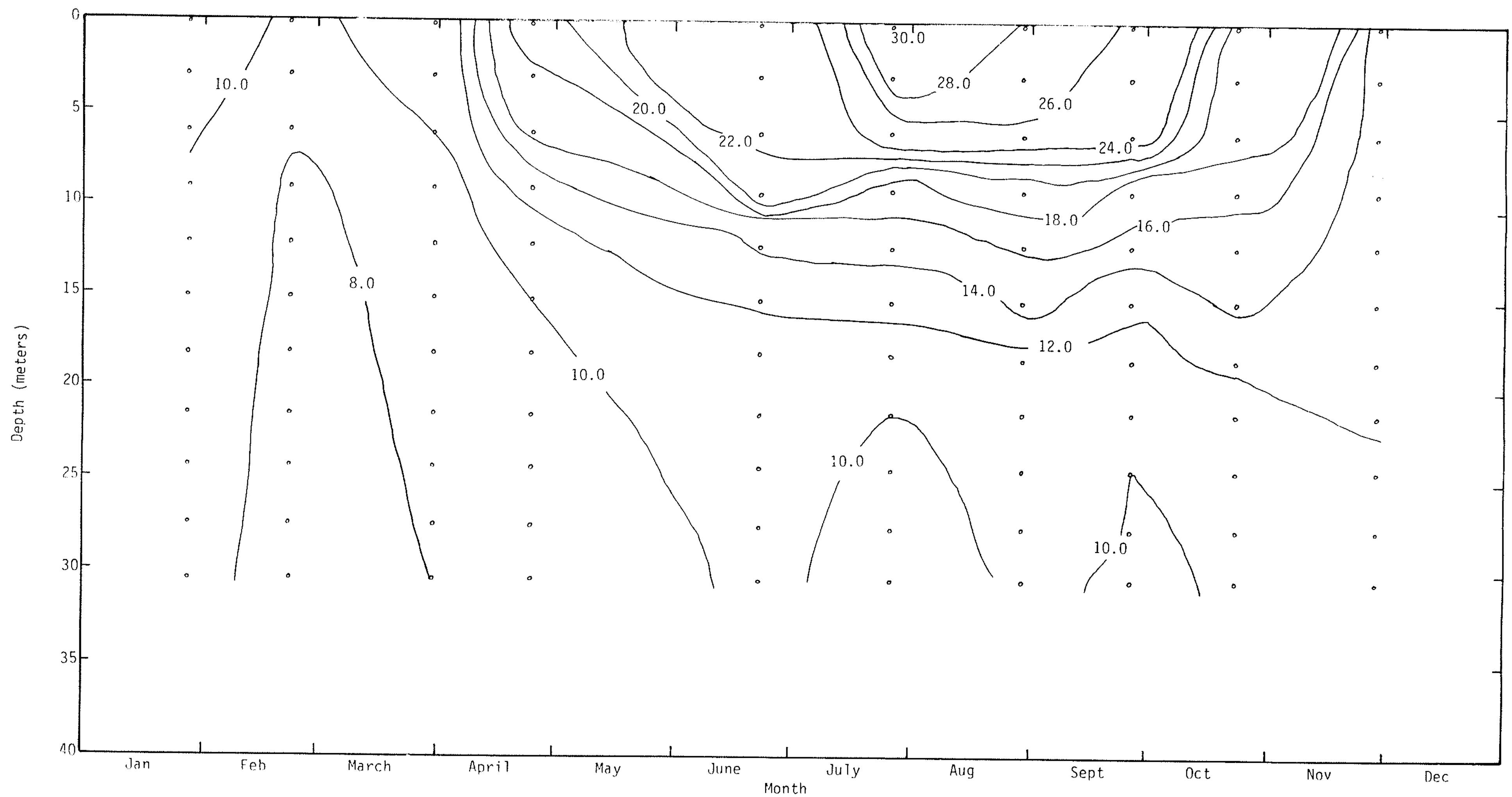


Figure 2 - 4 Temperature Isopleths (C) for Location 501.0 on Lake Keowee for 1972

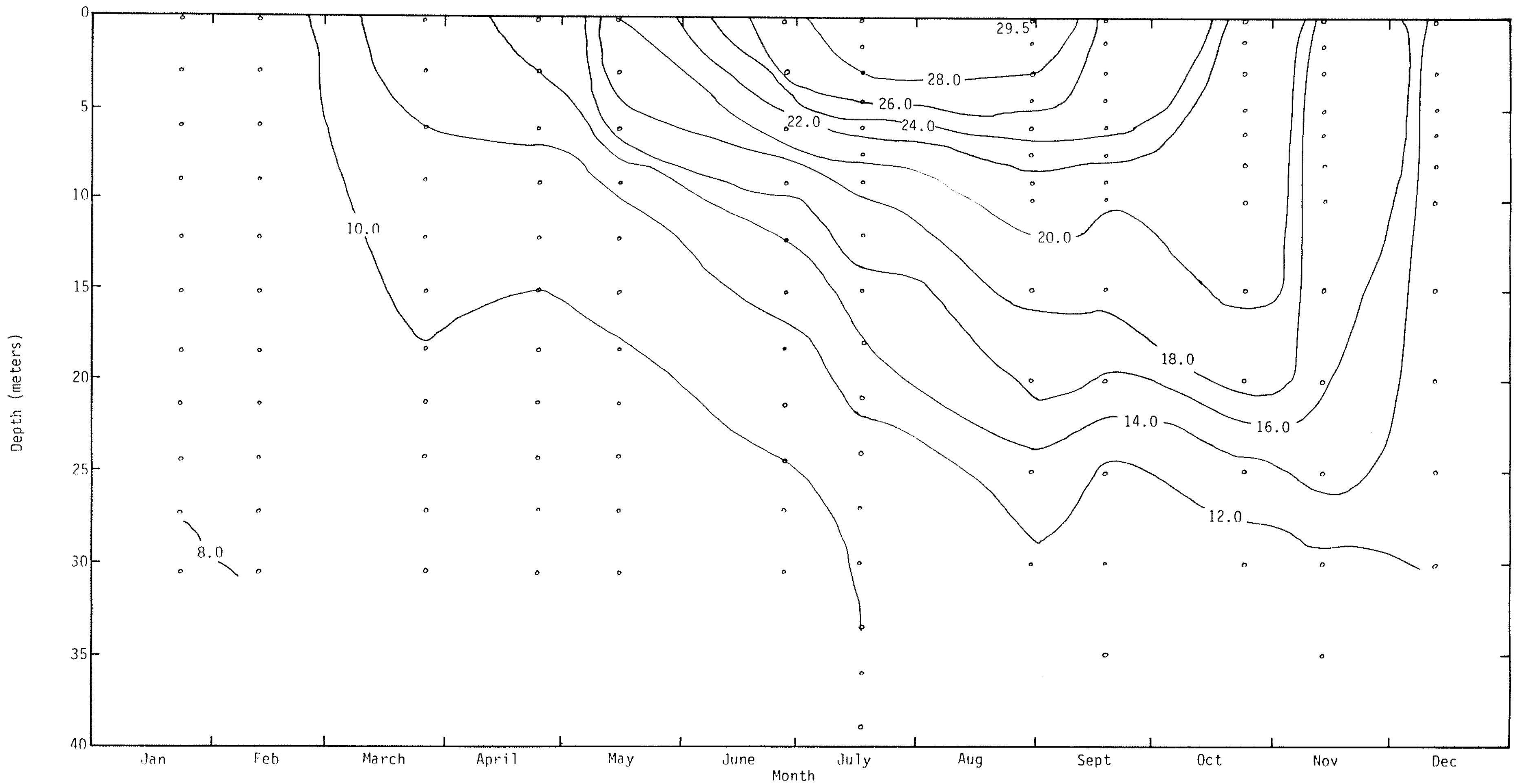


Figure 2 - 5 Temperature Isopleths (C) for Location 501.0 on Lake Keowee for 1973

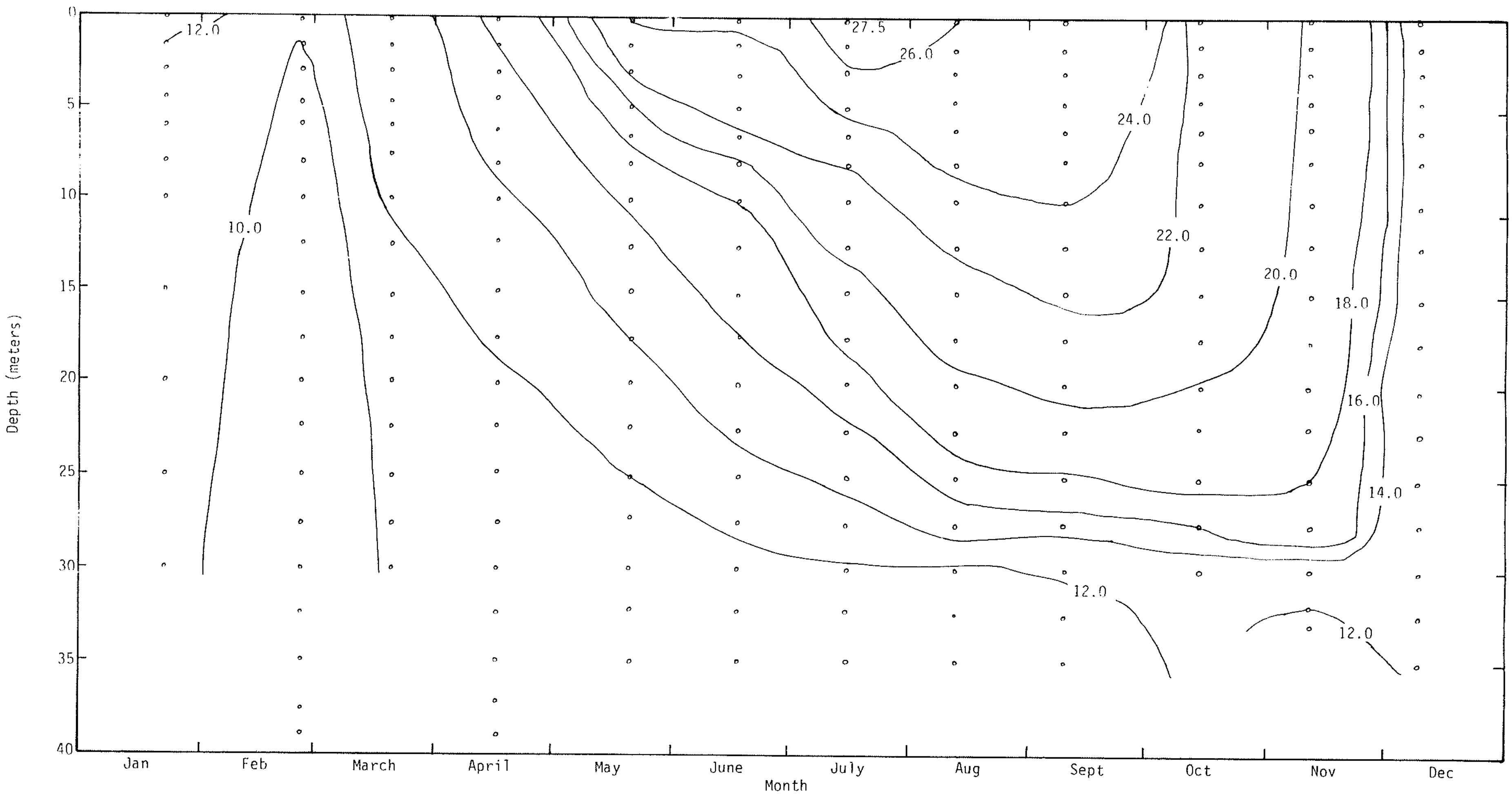


Figure 2 - 6 Temperature Isopleths (C) for Location 501.0 on Lake Keowee for 1974

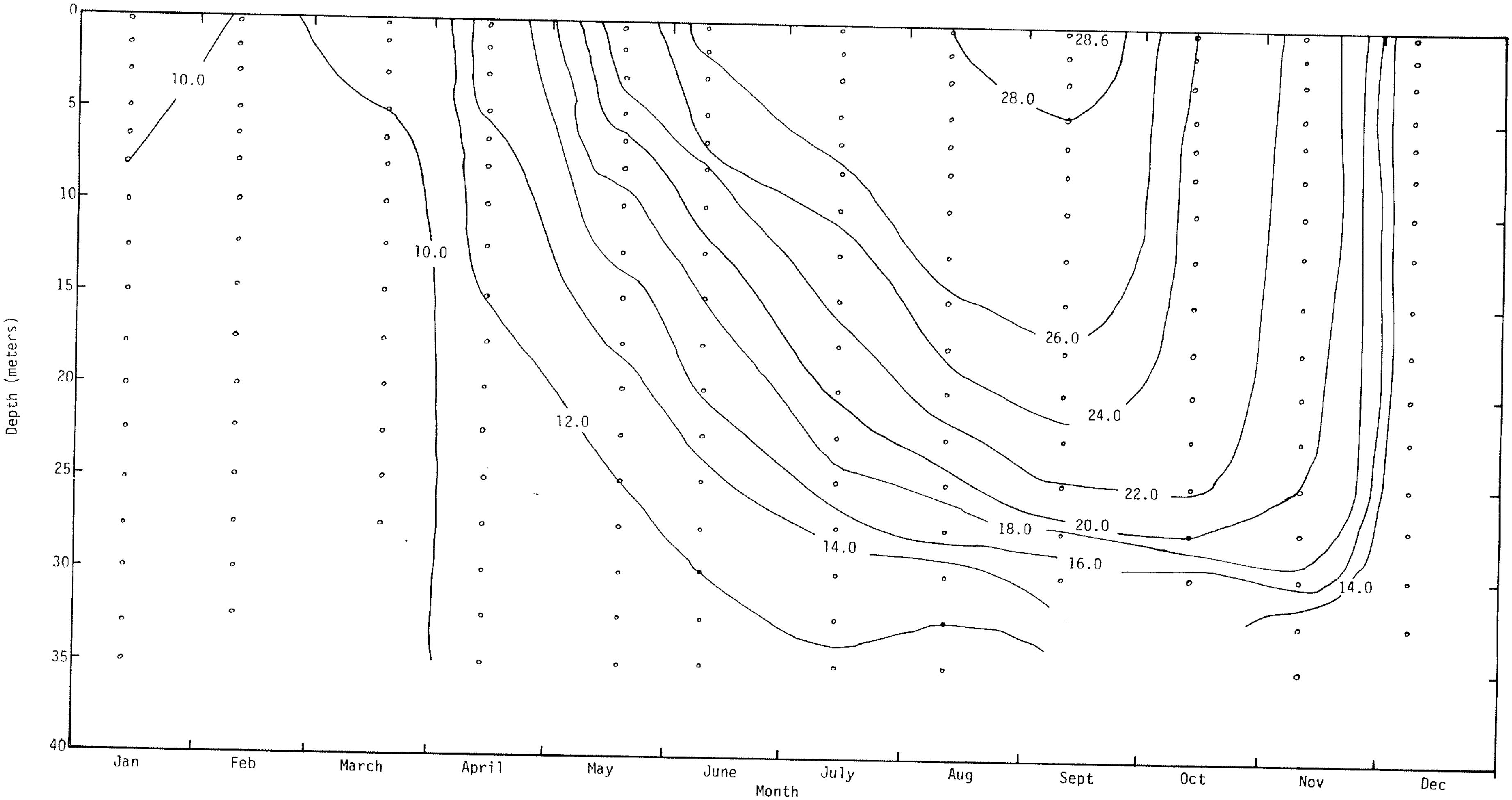


Figure 2 - 7 Temperature Isopleths (C) for Location 501.0 on Lake Keowee for 1975

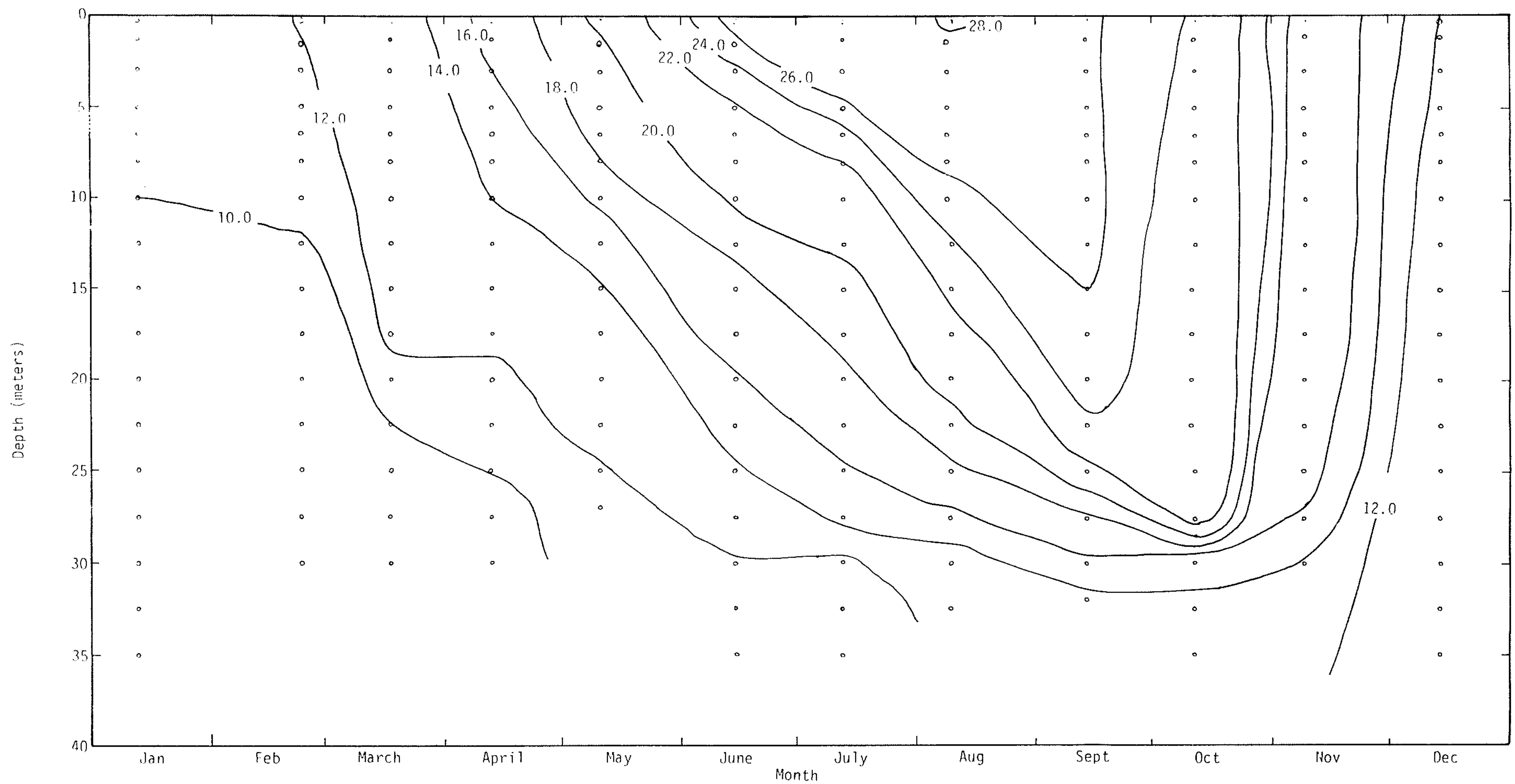


Figure 2 - 8 Temperature Isopleths (C) for Location 501.0 on Lake Keowee for 1976

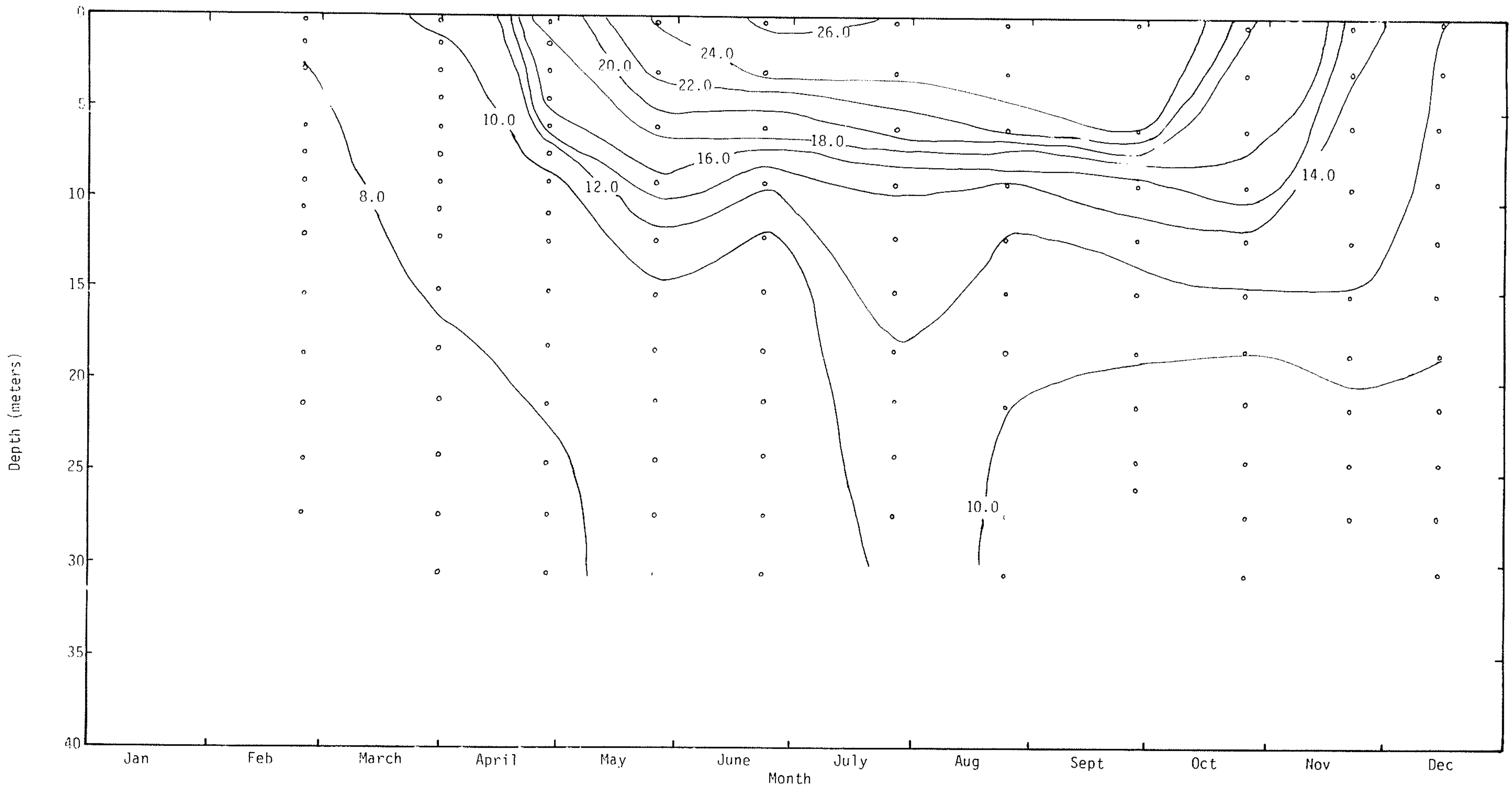


Figure 2 - 9 Temperature Isopleths (C) for Location 502.0 on Lake Keowee for 19/1

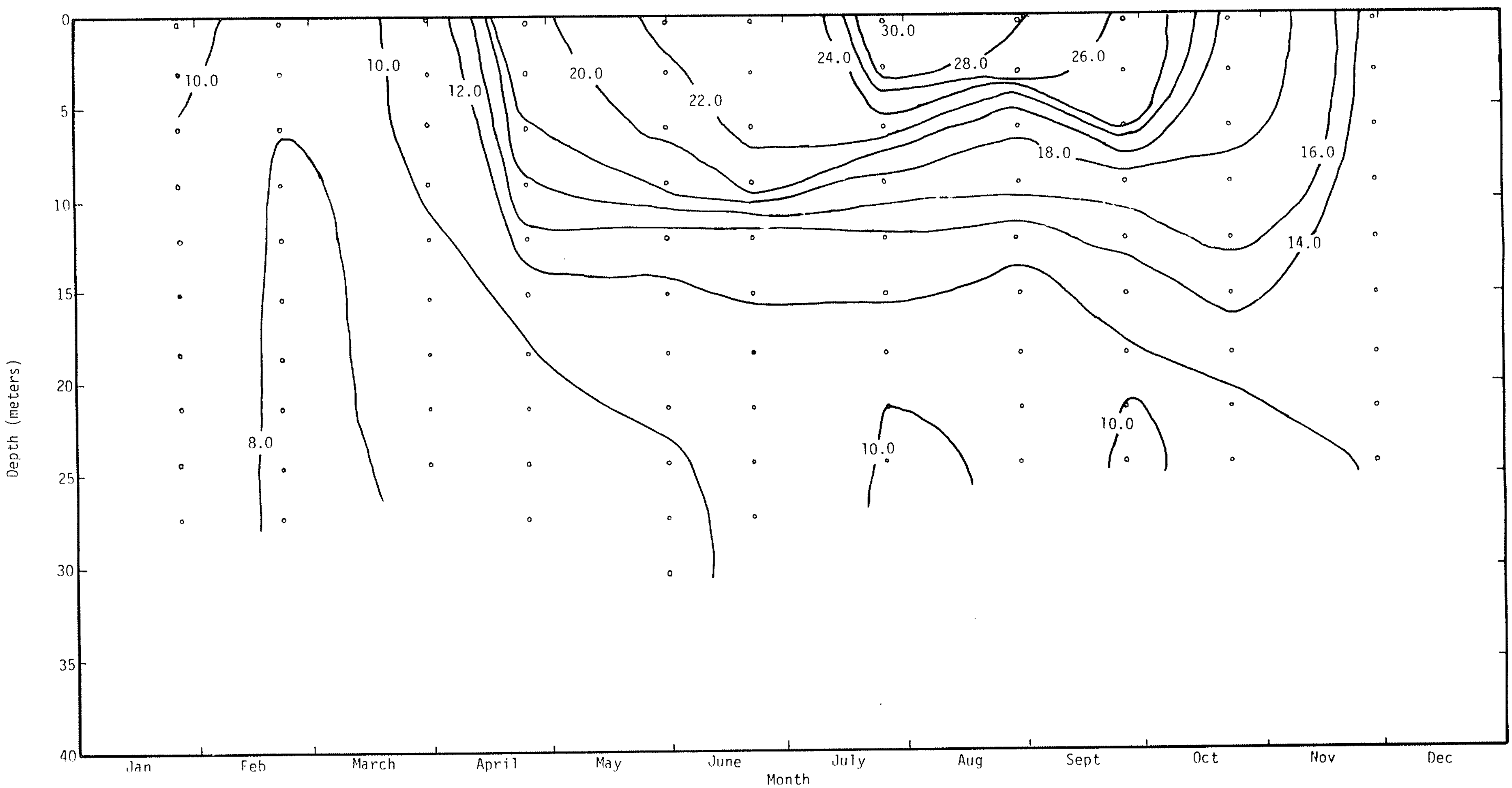


Figure 2 - 10 Temperature Isopleths (C) for Location 502.0 on Lake Keowee for 19.2

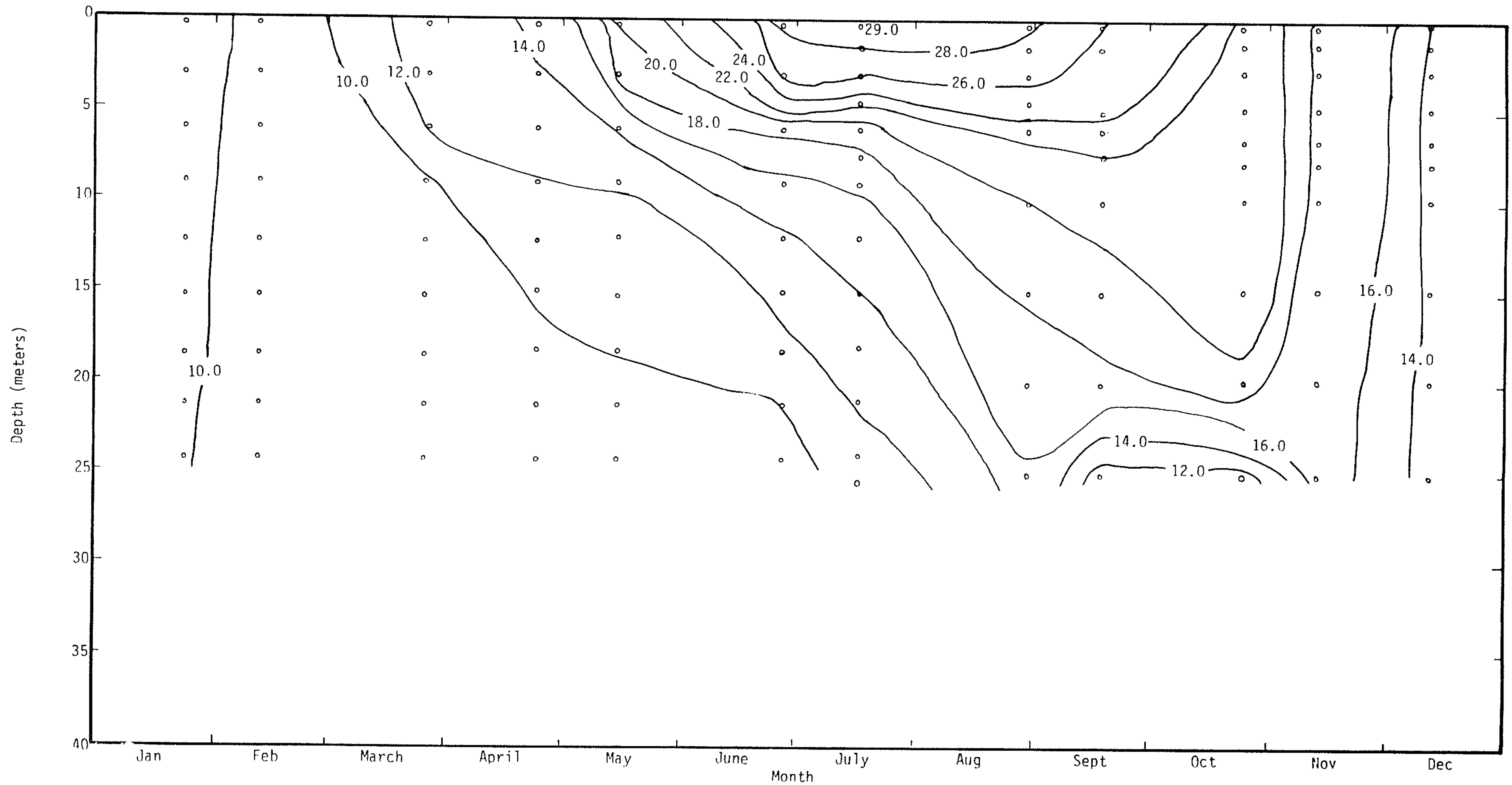


Figure 2 - II Temperature Isopleths **(C)** for Location 502.0 on Lake Keowee for 1973

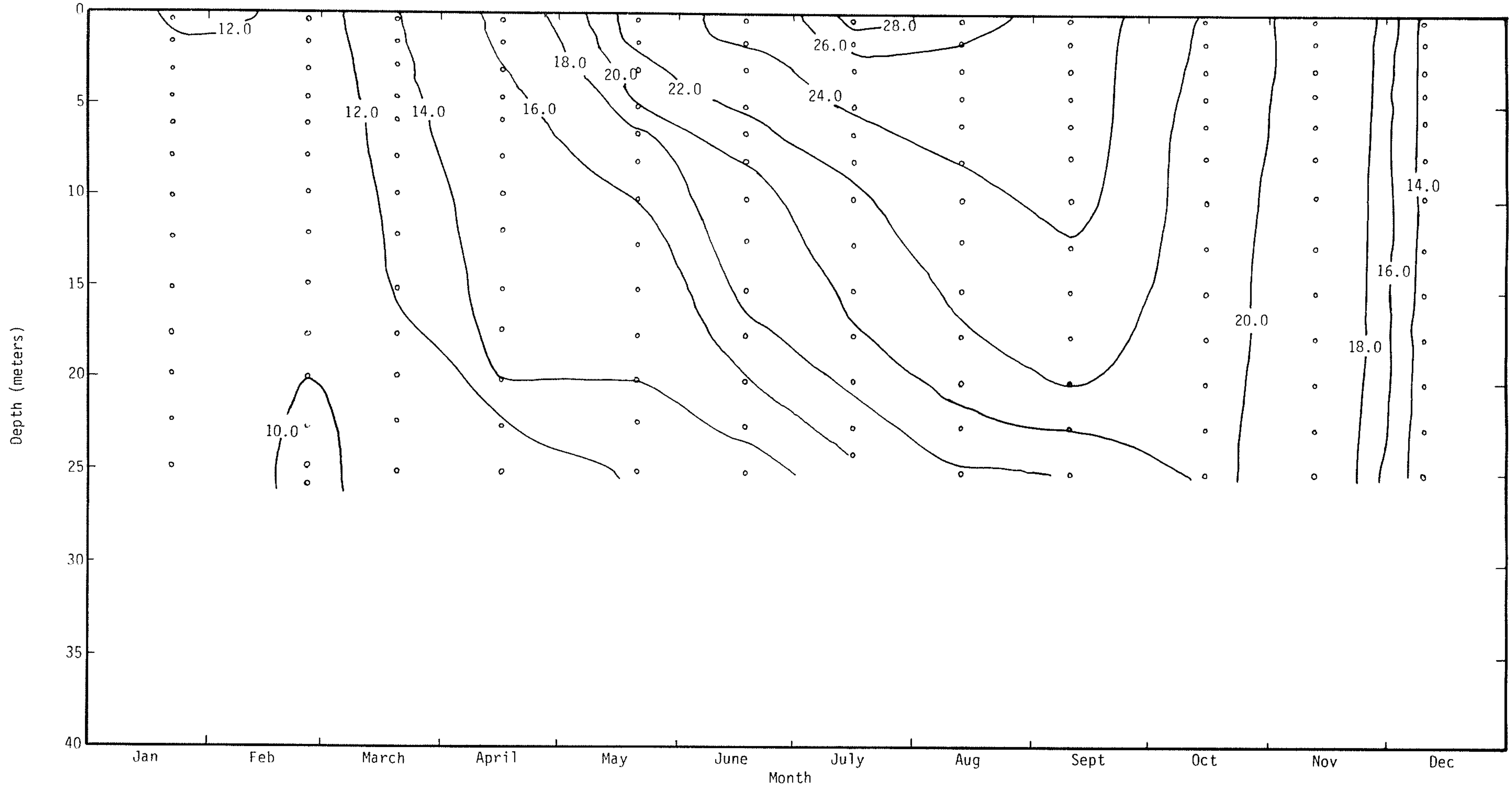


Figure 2 - 12 Temperature Isopleths (C) for Location 502.0 on Lake Keowee for 1974

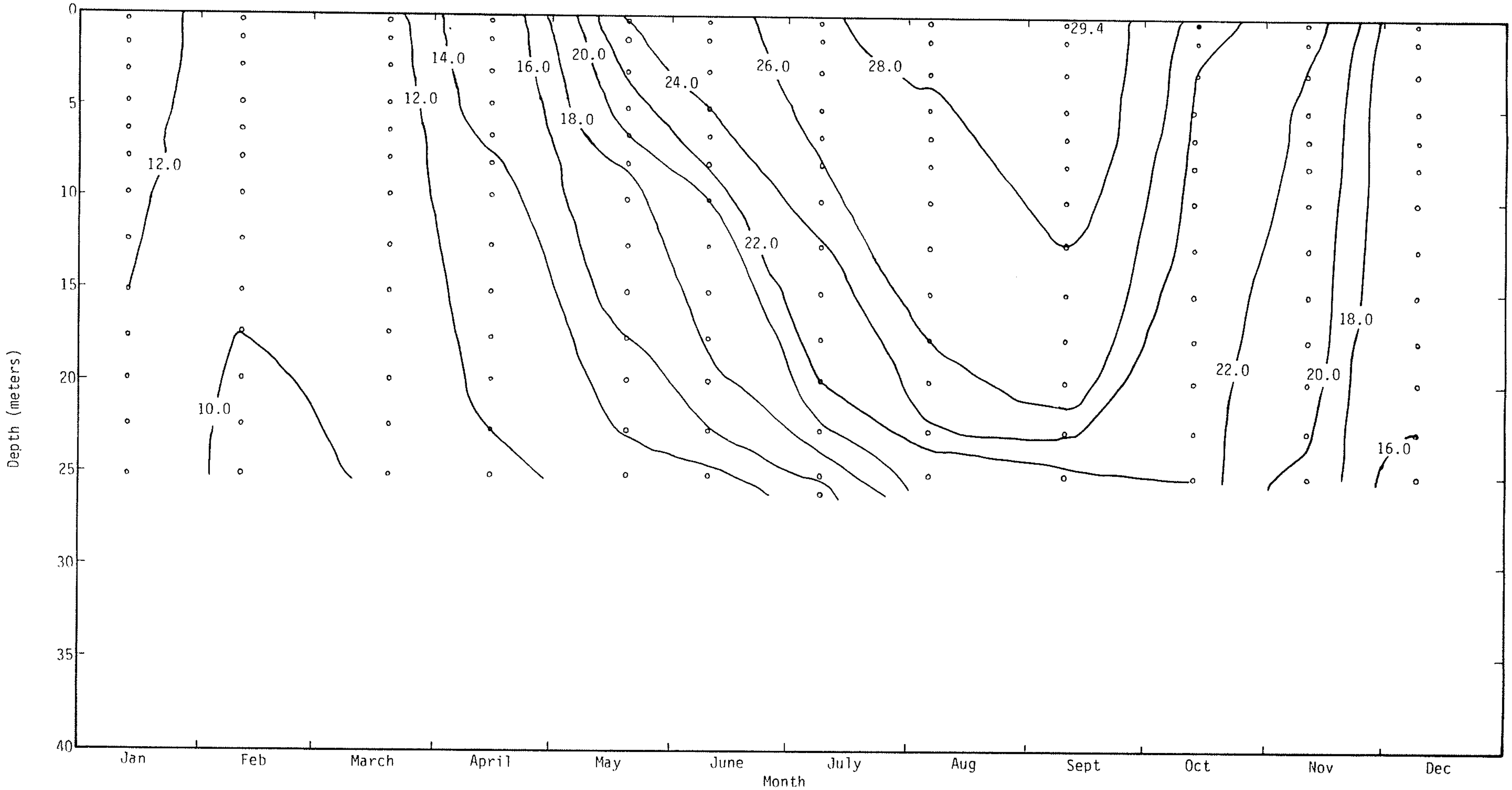


Figure 2 - 13 Temperature Isopleths (C) for Location 502.0 on Lake Keowee for 1975

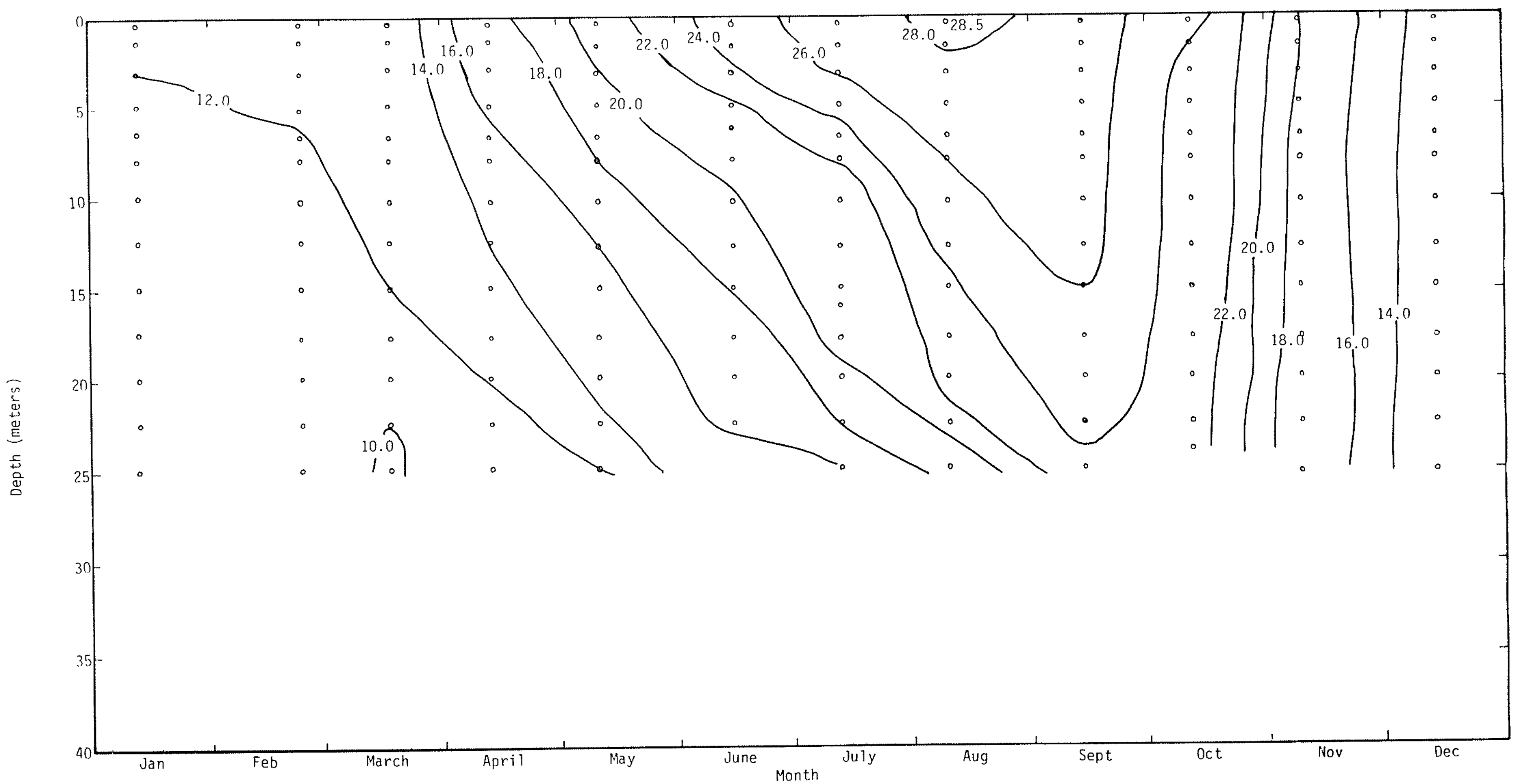


Figure 2 -14 Temperature Isopleths (C) for Location 502.0 on Lake Keowee for 1976

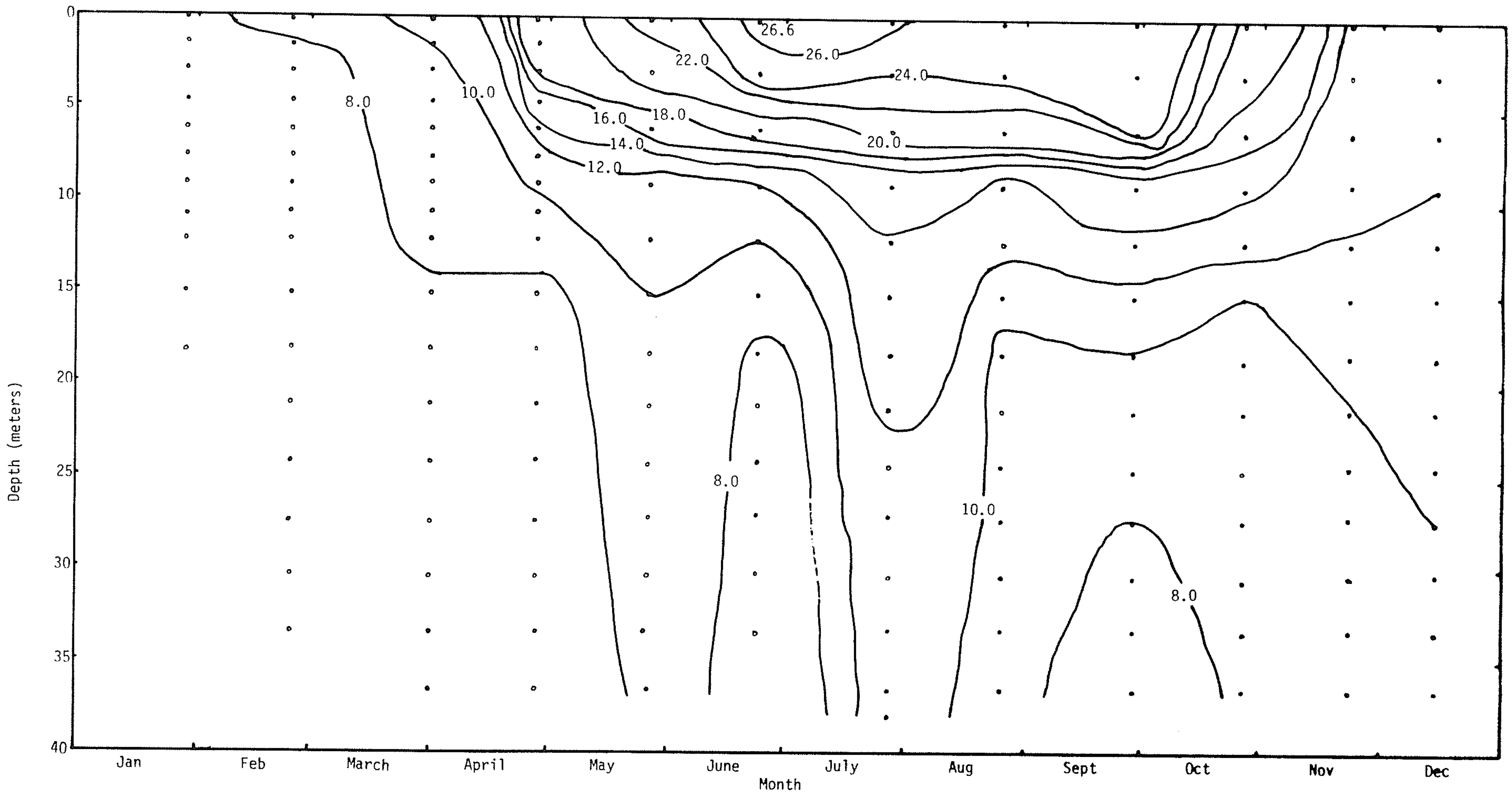


Figure 2 - 15 Temperature Isopleths (C) for Location 504.0 on Lake Keowee for 19/1

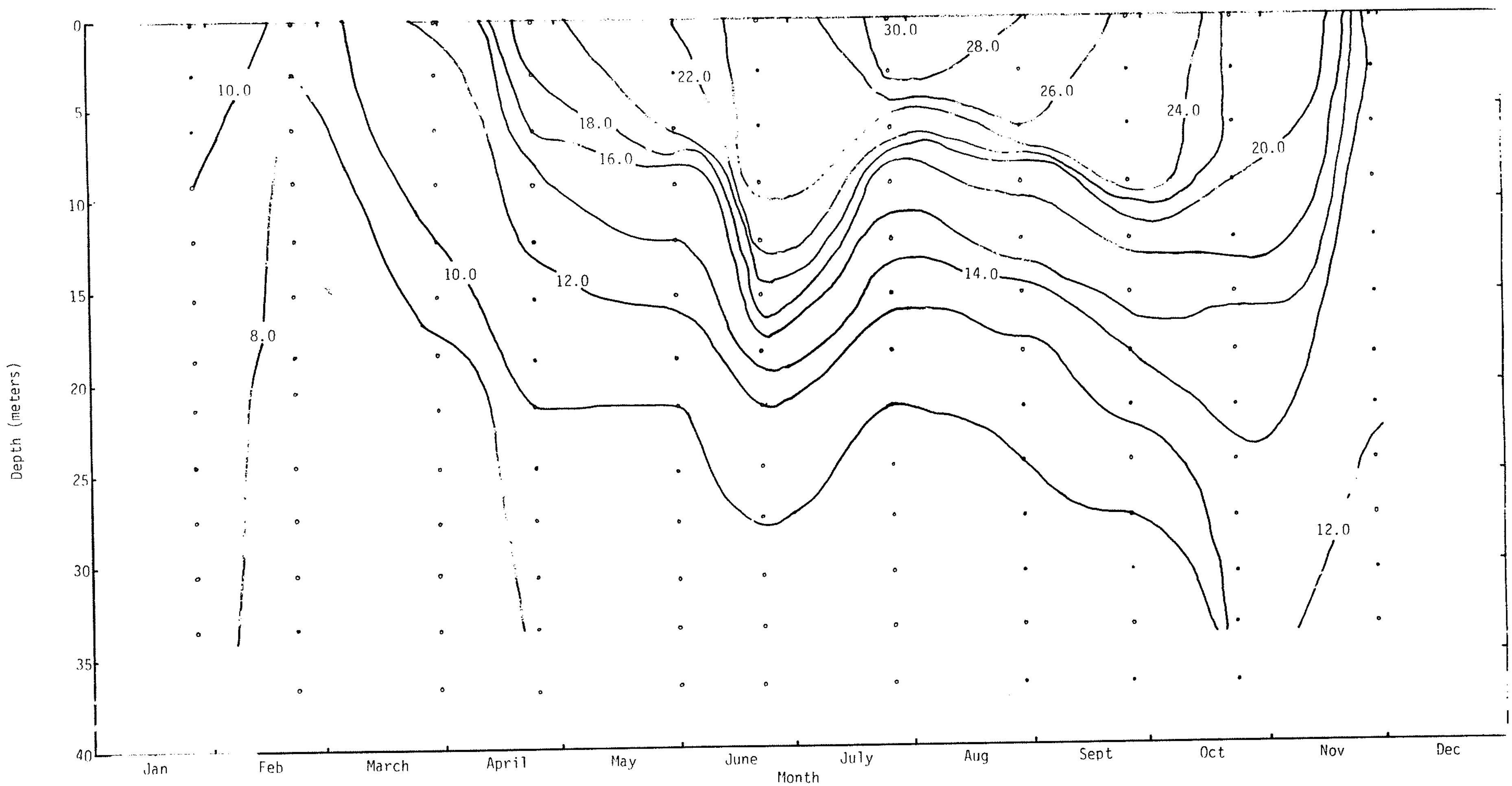


Figure 2 - 16 Temperature Isopleths (C) for Location 504.0 on Lake Keowee for 1972

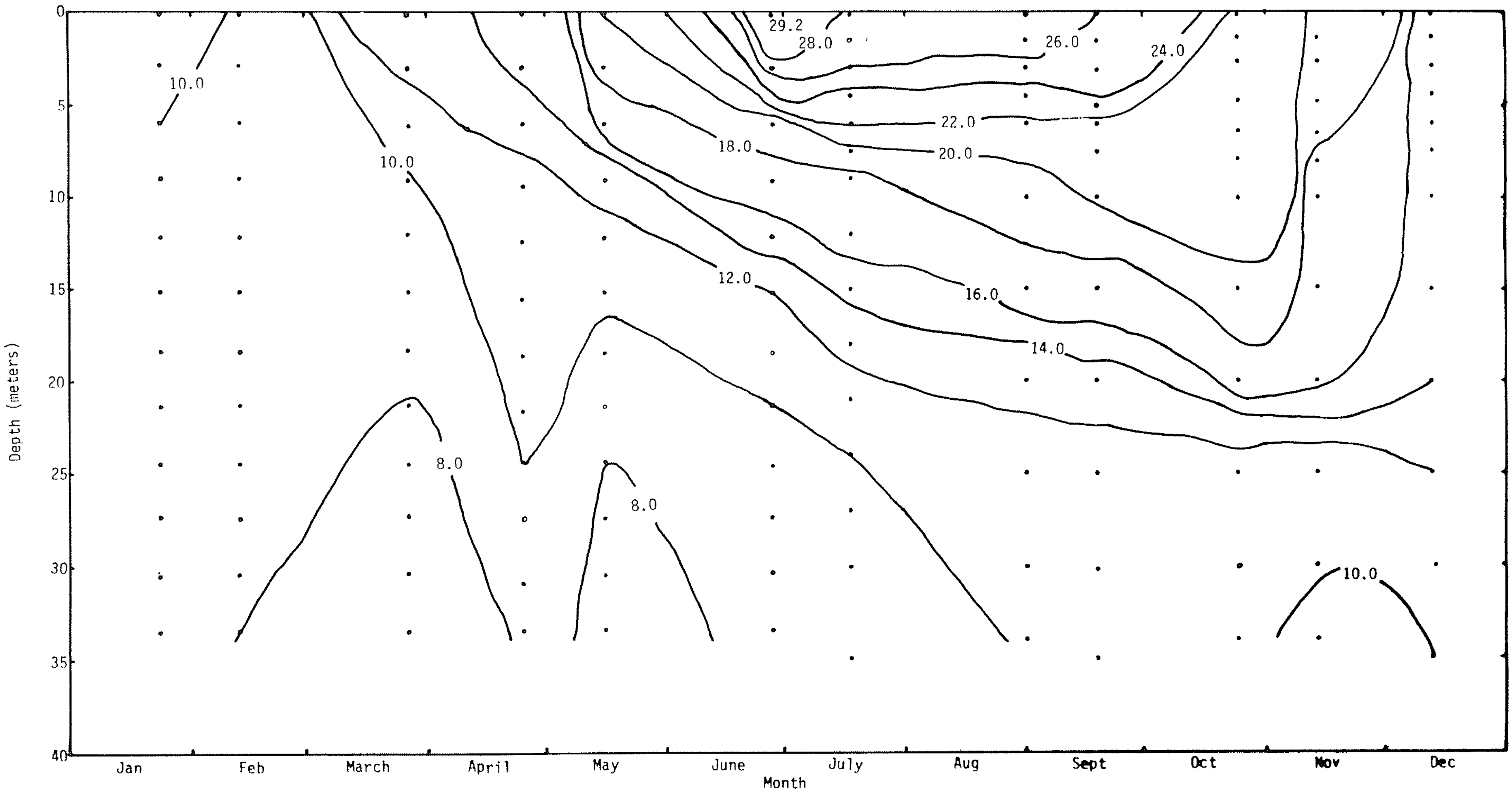


Figure 2 -17 Temperature Isopleths (C) for Location
504.0 on Lake Keowee for 1973

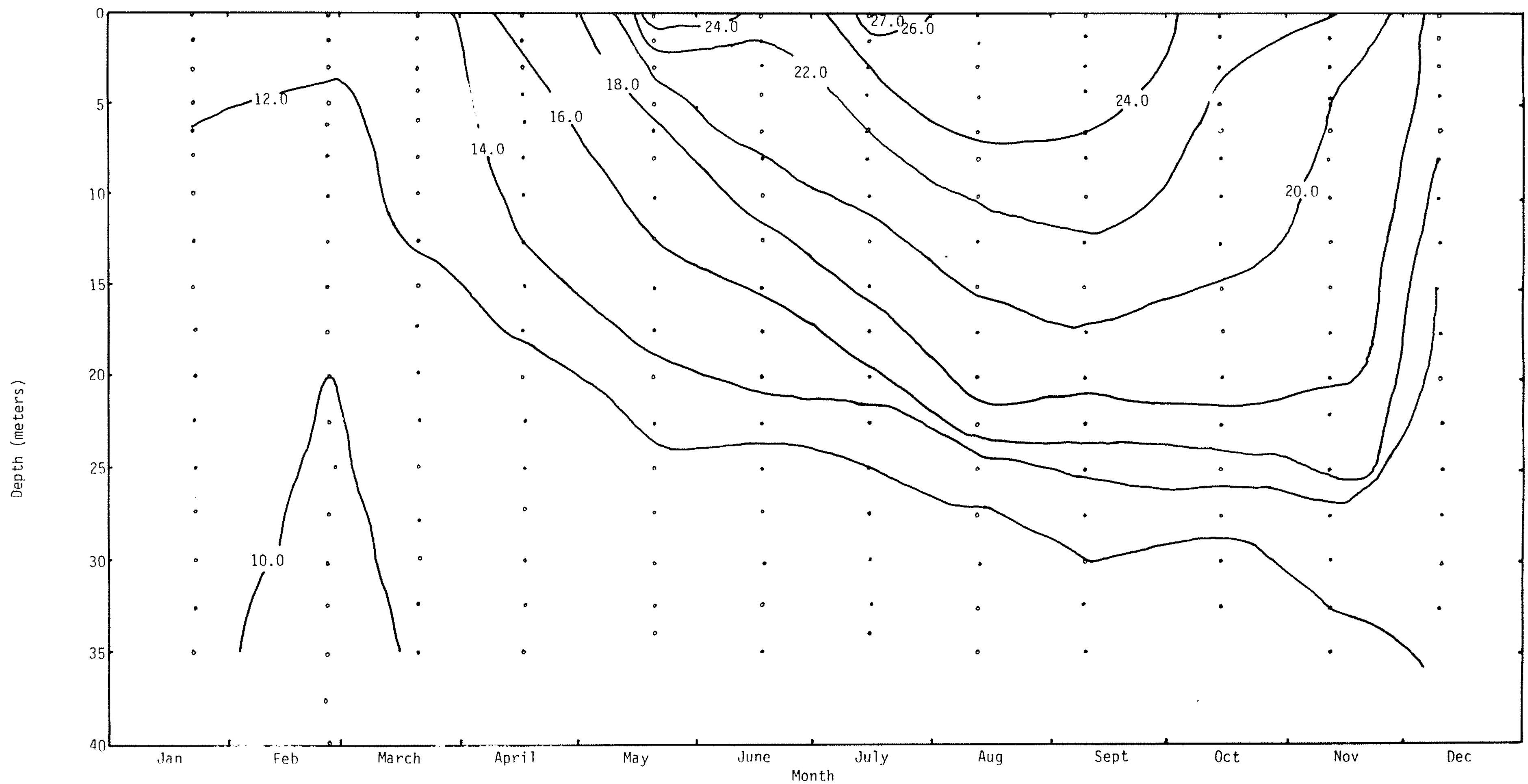


Figure 2 -18 Temperature Isopleths (C) for Location 504.0 on Lake Keowee for 1974

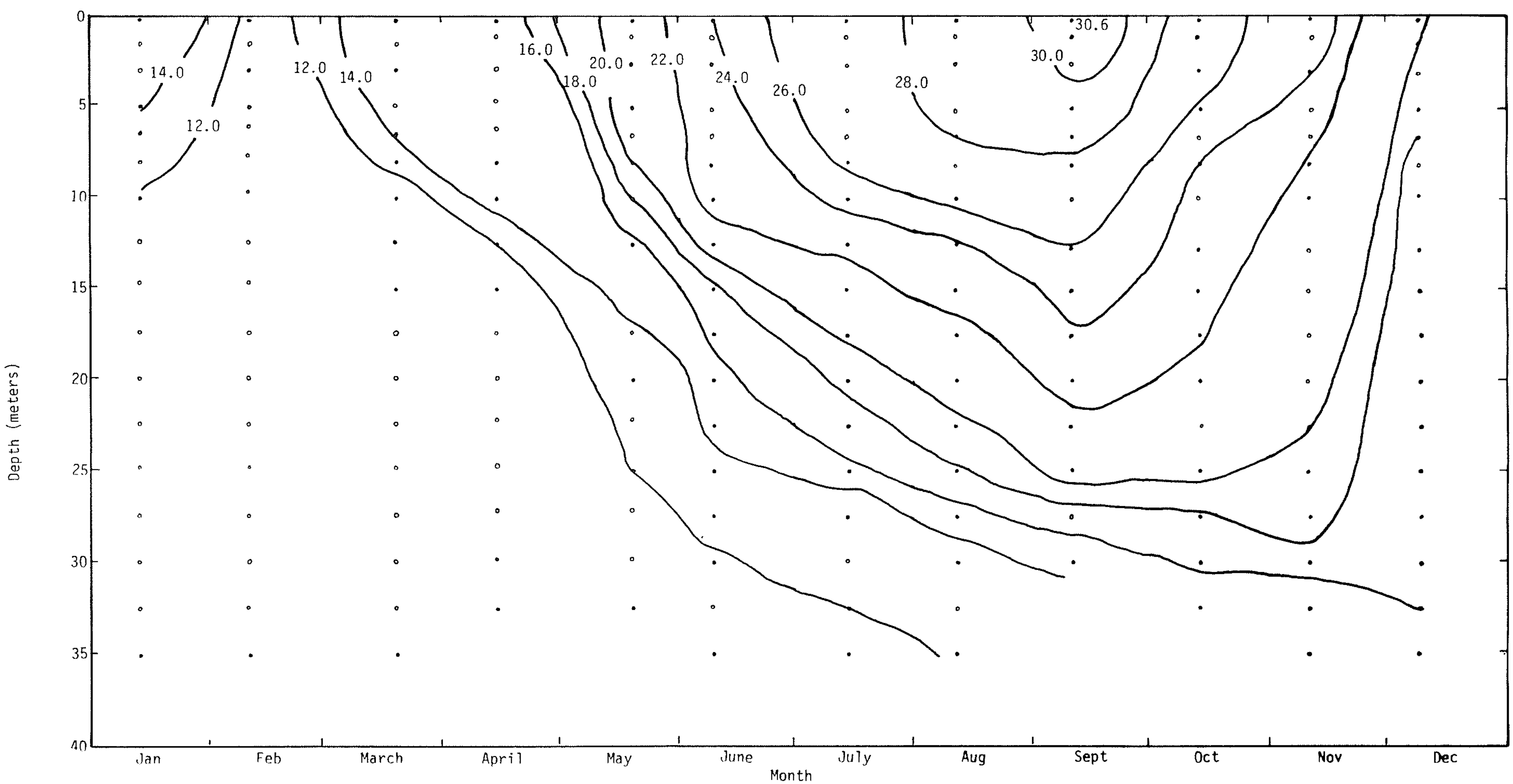


Figure 2 -19 Temperature Isopleths (C) for Location 504.0 on Lake Keowee for 1975

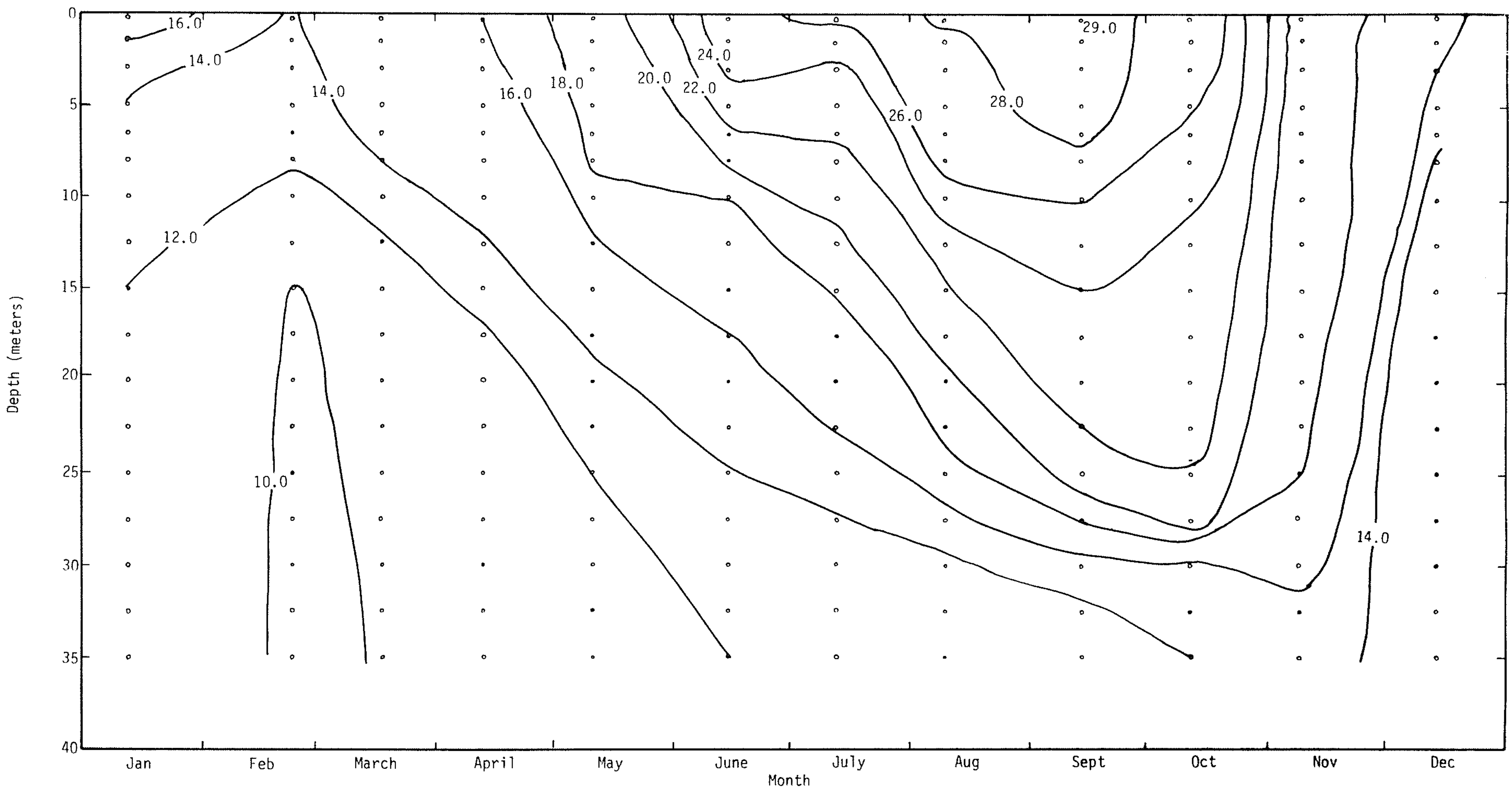


Figure 2 -20 Temperature Isopleths (C) for Location
504.0 on Lake Keowee for 1976

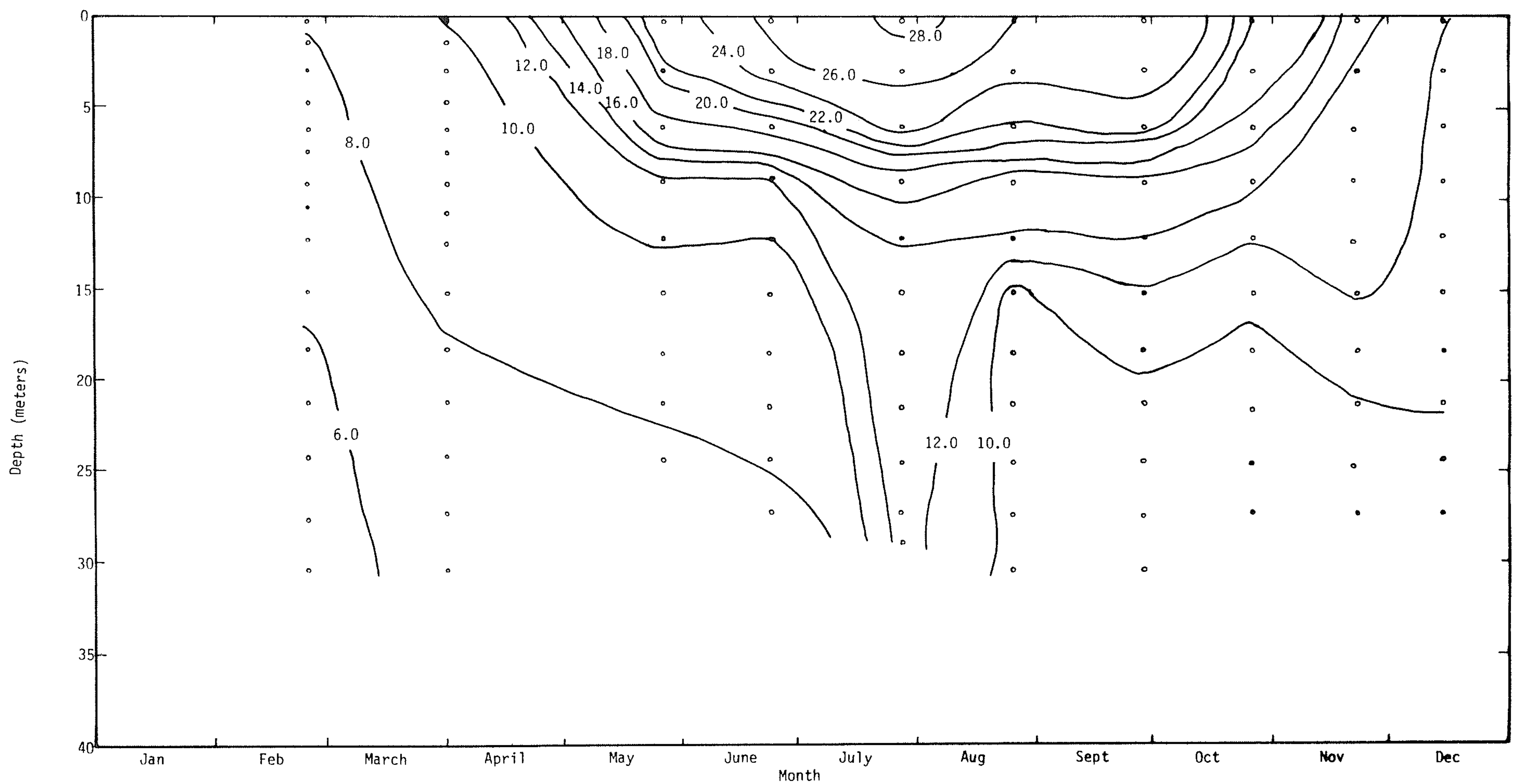


Figure 2 - 21 Temperature Isopleths (°C) for Location 506.0 on Lake Keowee for 1971

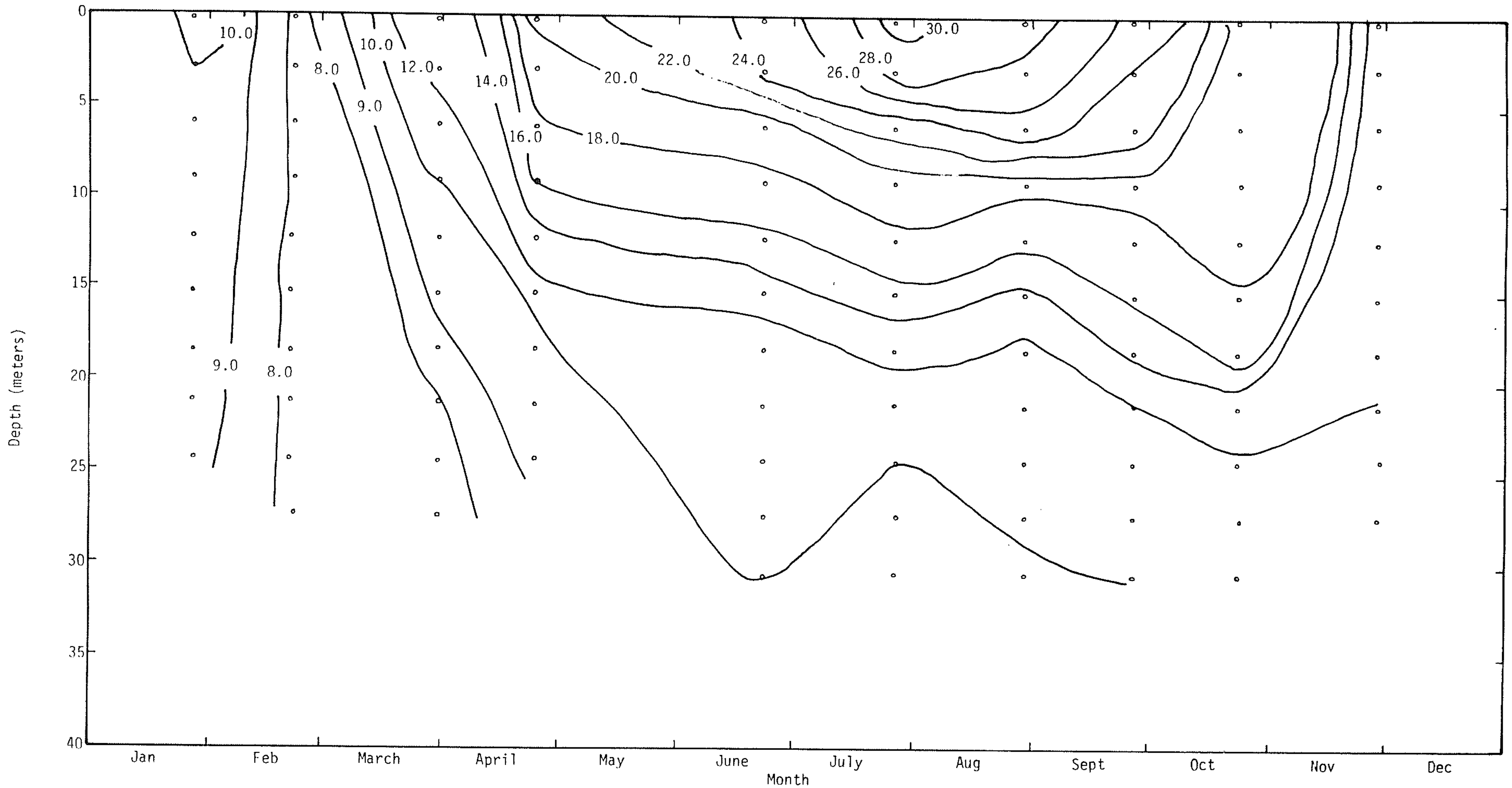


Figure 2 - 22 Temperature Isopleths (C) for Location 506.0 on Lake Keowee for 1972

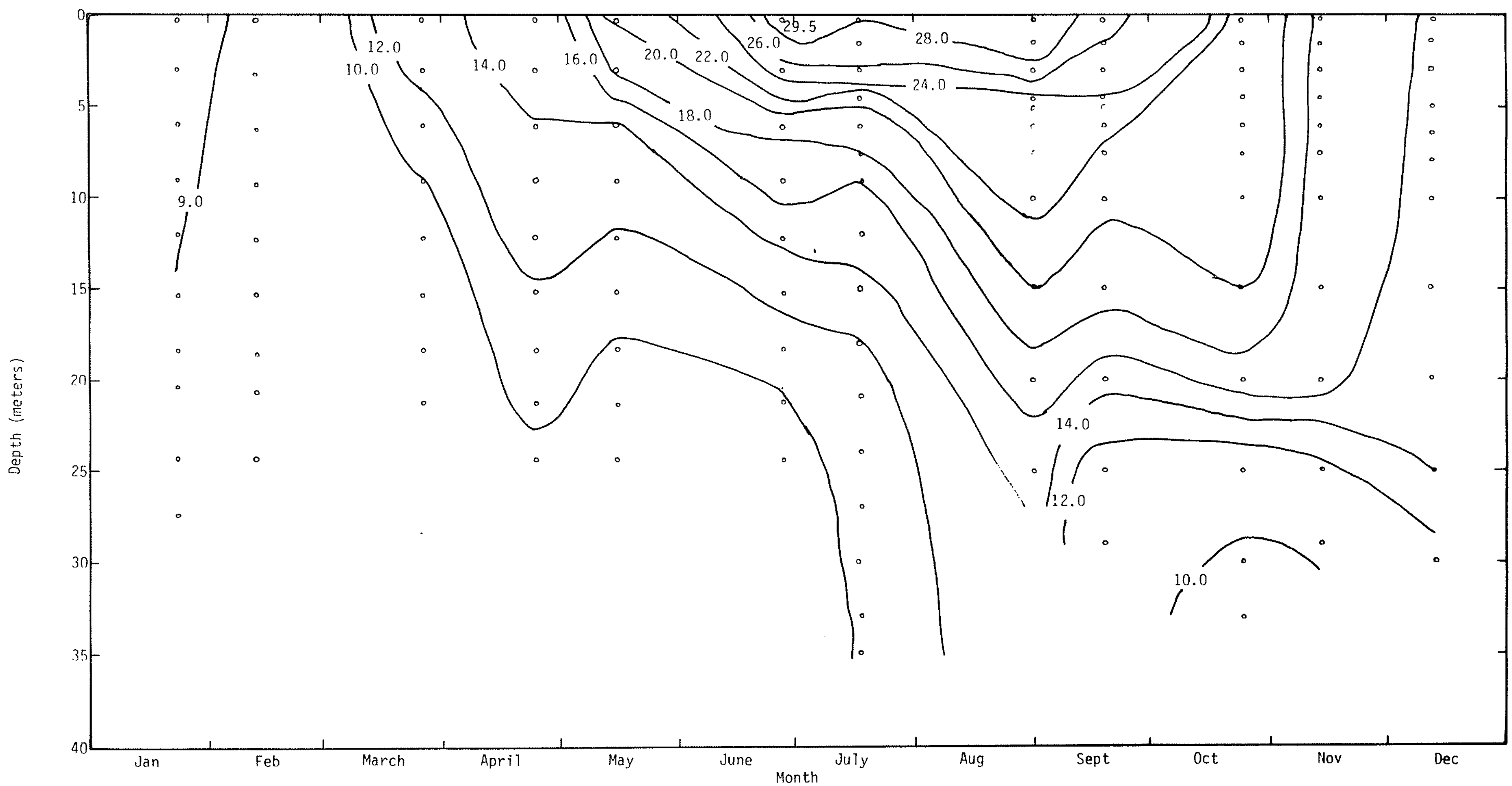


Figure 2 - 23 Temperature Isopleths (C) for Location 506.0 on Lake Keowee for 1973

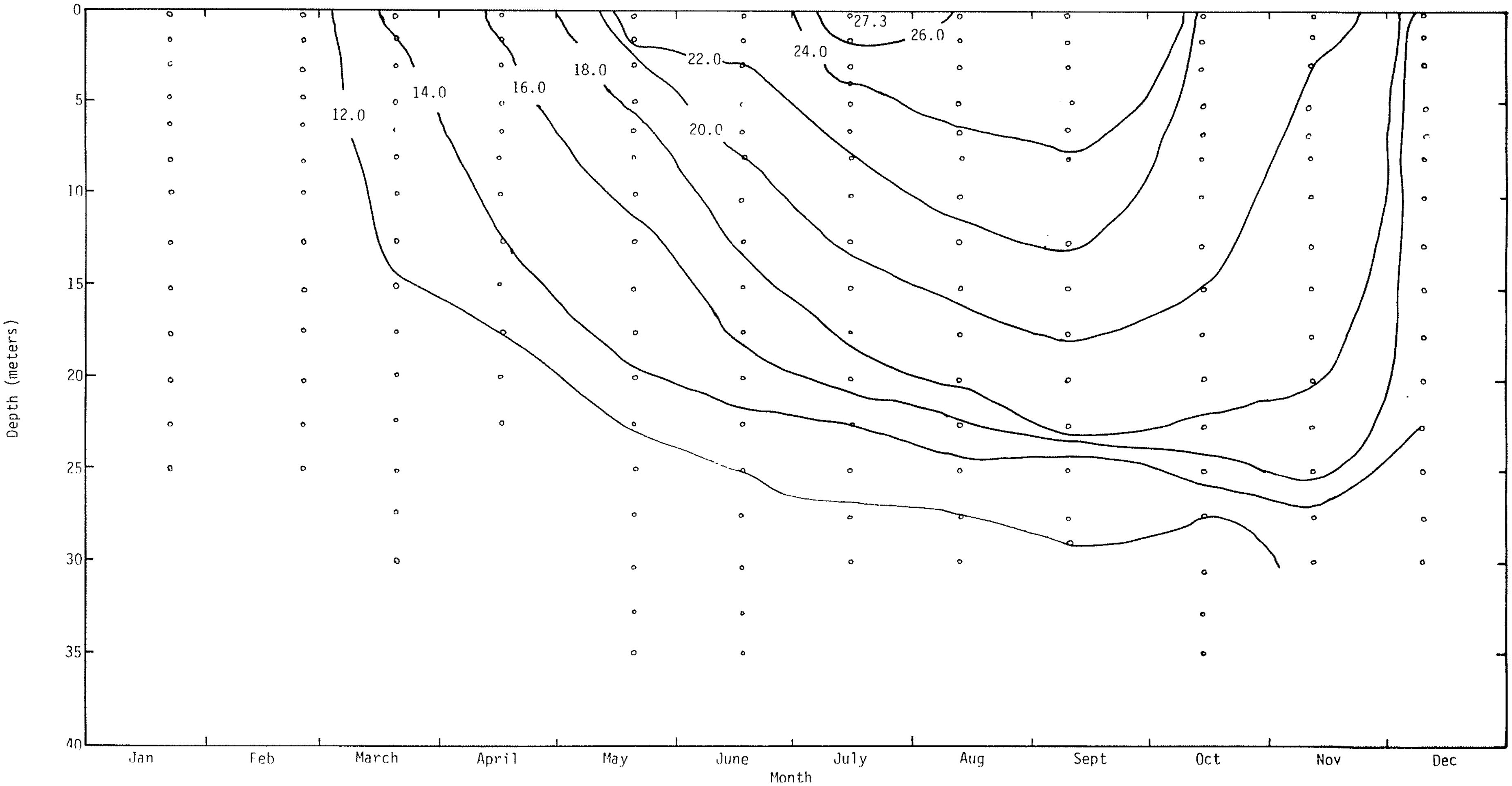


Figure 2 - 24 Temperature Isopleths (C) for Location 506.0 on Lake Keowee for 1974

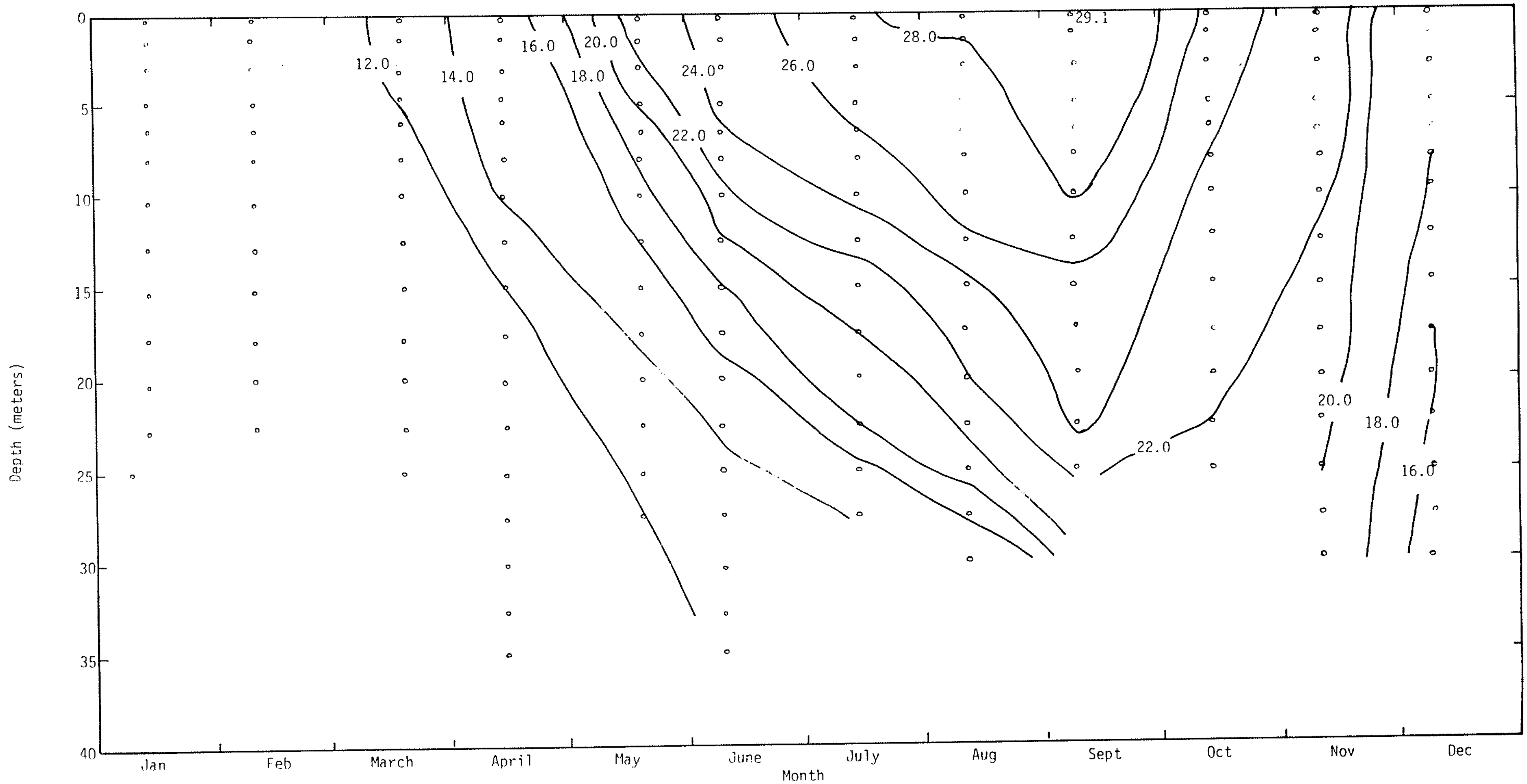


Figure 2 - **25** Temperature Isopleths (**C**) for Location 506.0 on Lake Keowee for 19/5

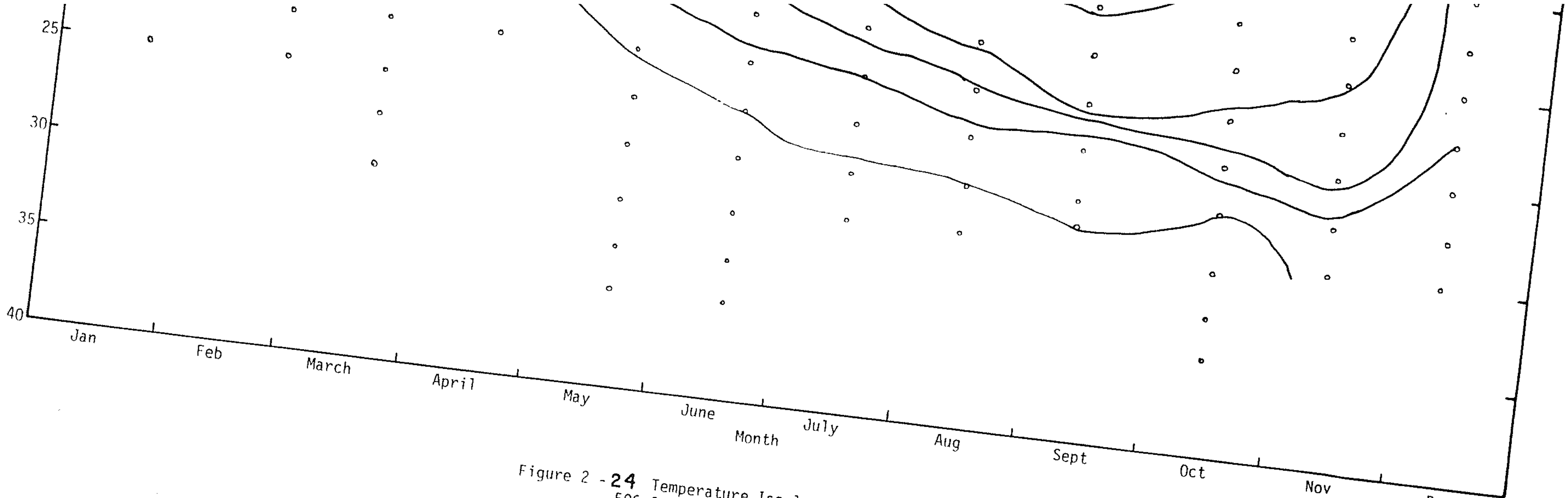


Figure 2 - 24 Temperature Isopleths (C) for Location 506.0 on Lake Keowee for 19/4

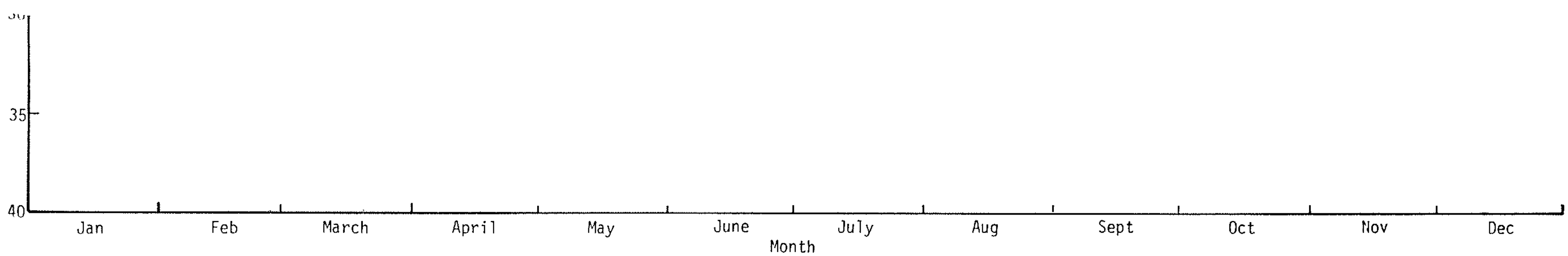


Figure 2 - 26 Temperature Isopleths (C) for Location 506.0 on Lake Keowee for 1976

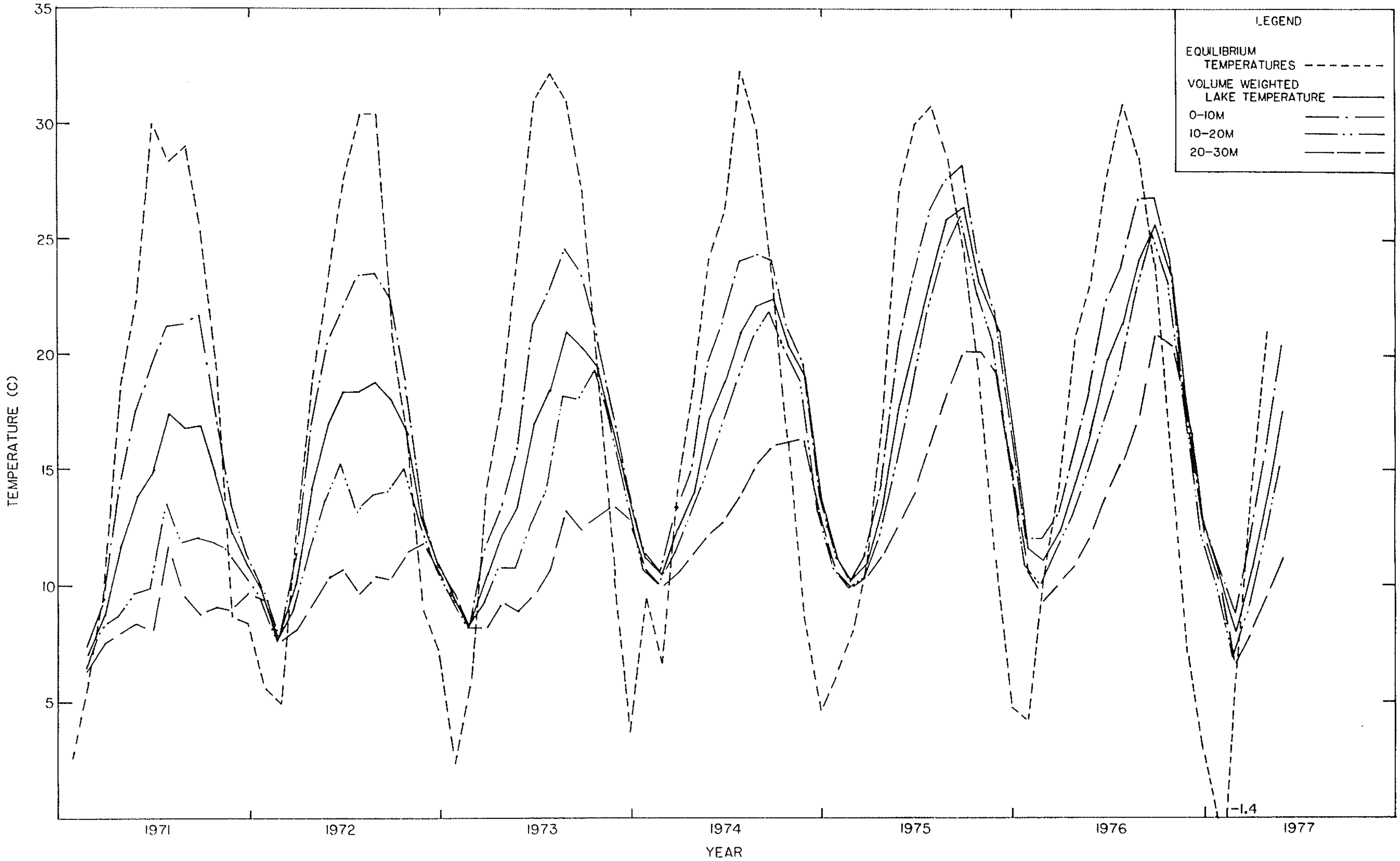
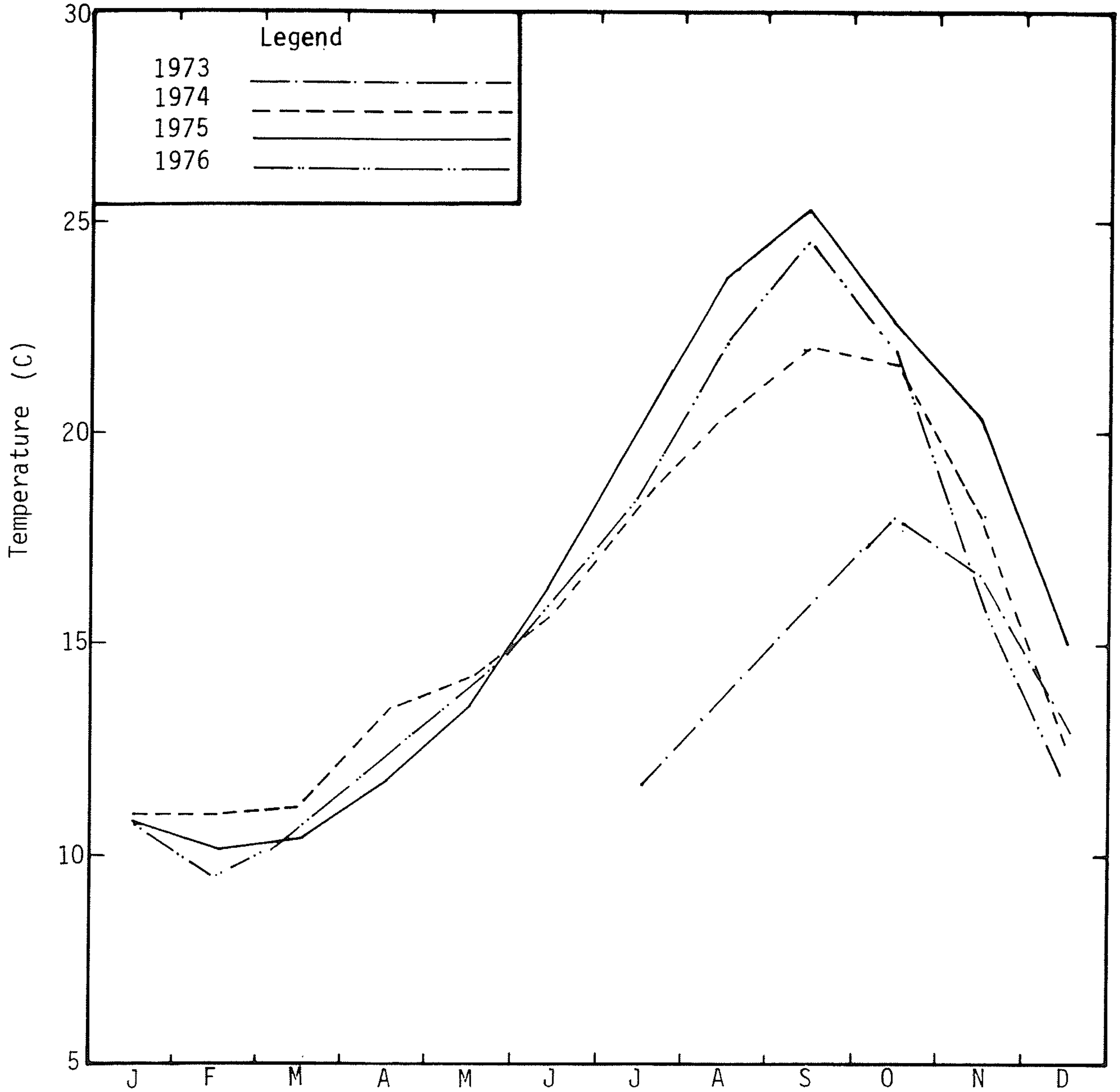


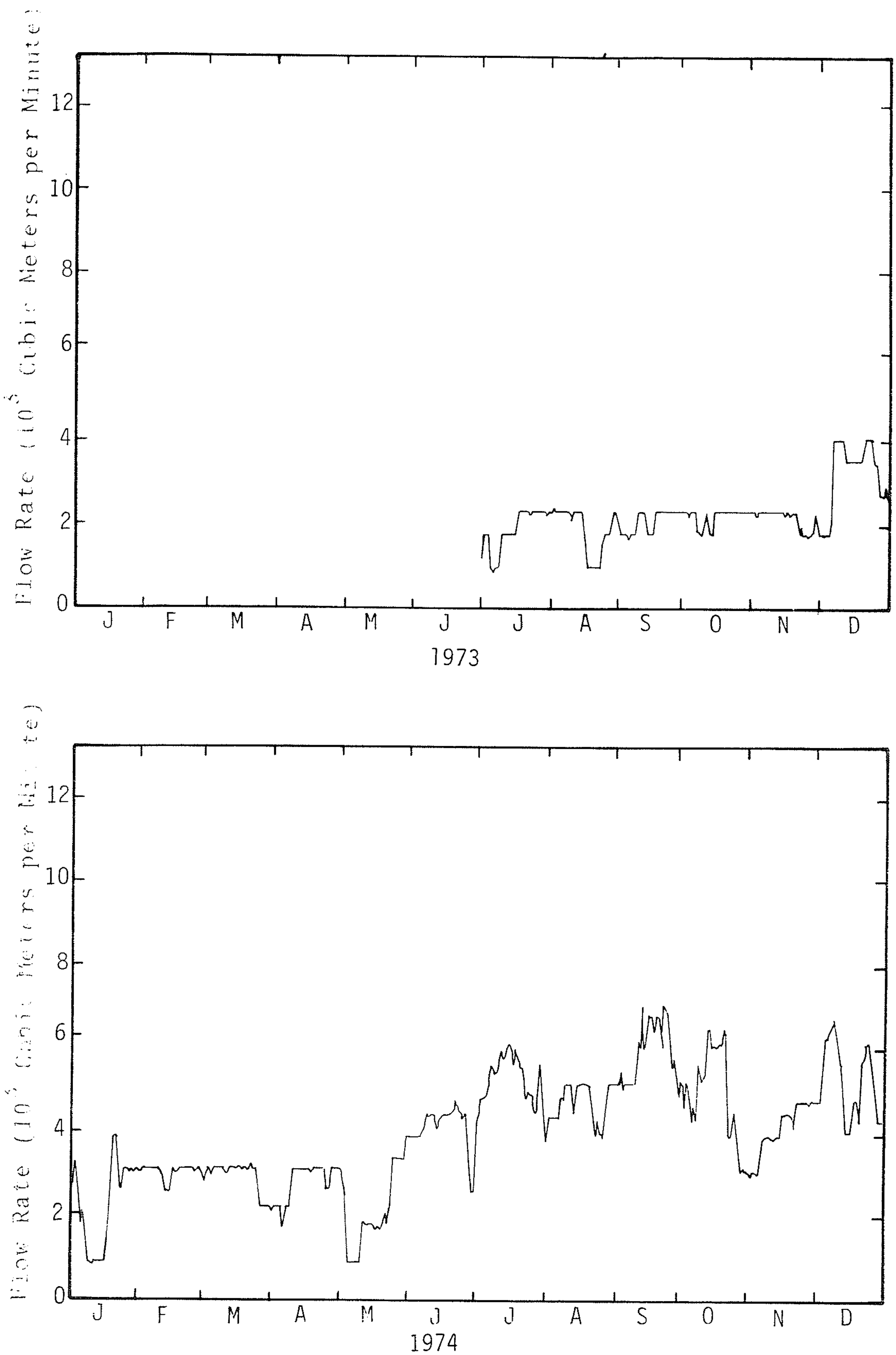
Figure: 2-27

Lake Keowee Average Temperatures

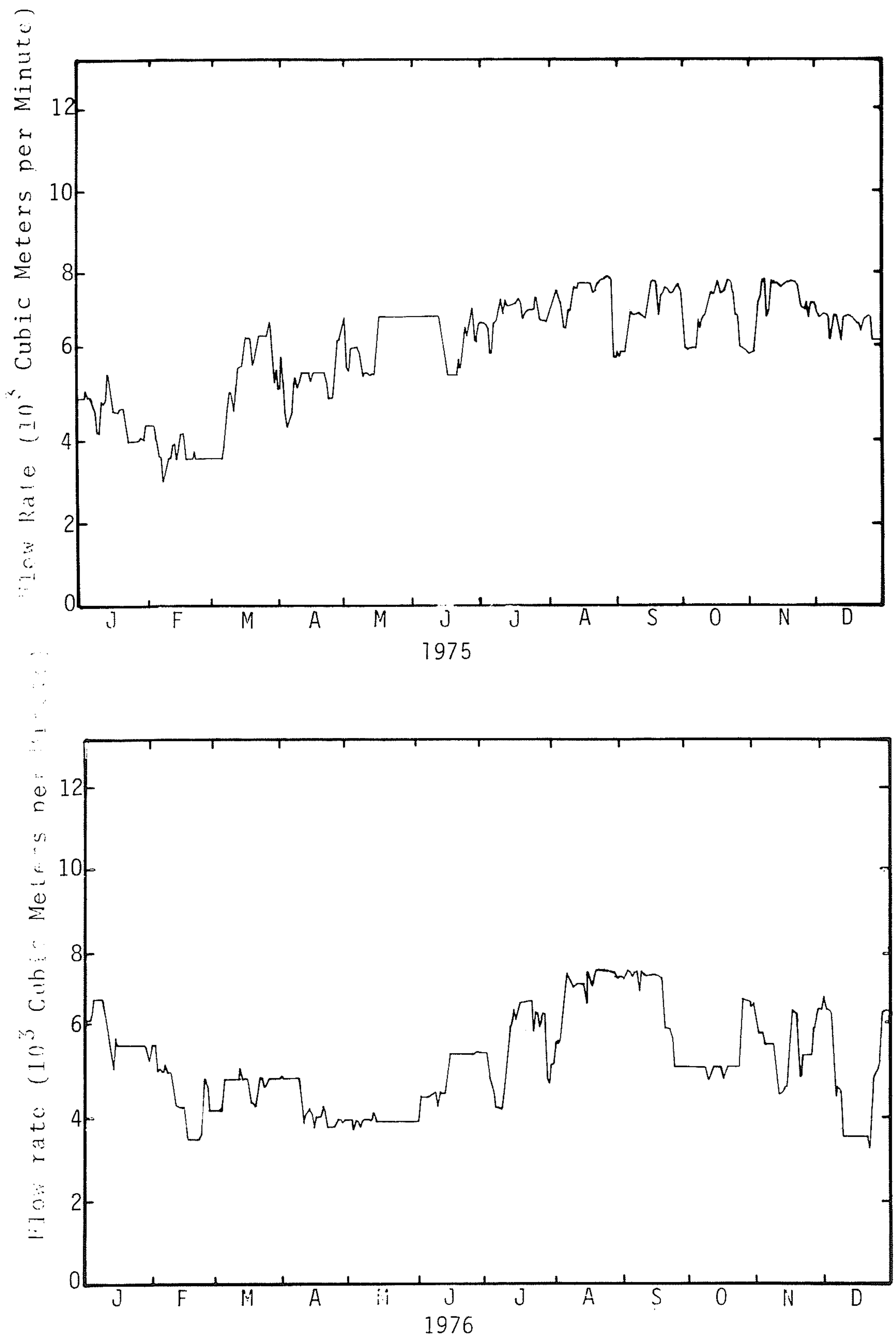


Monthly Mean of the Daily Average Inlet Temperatures

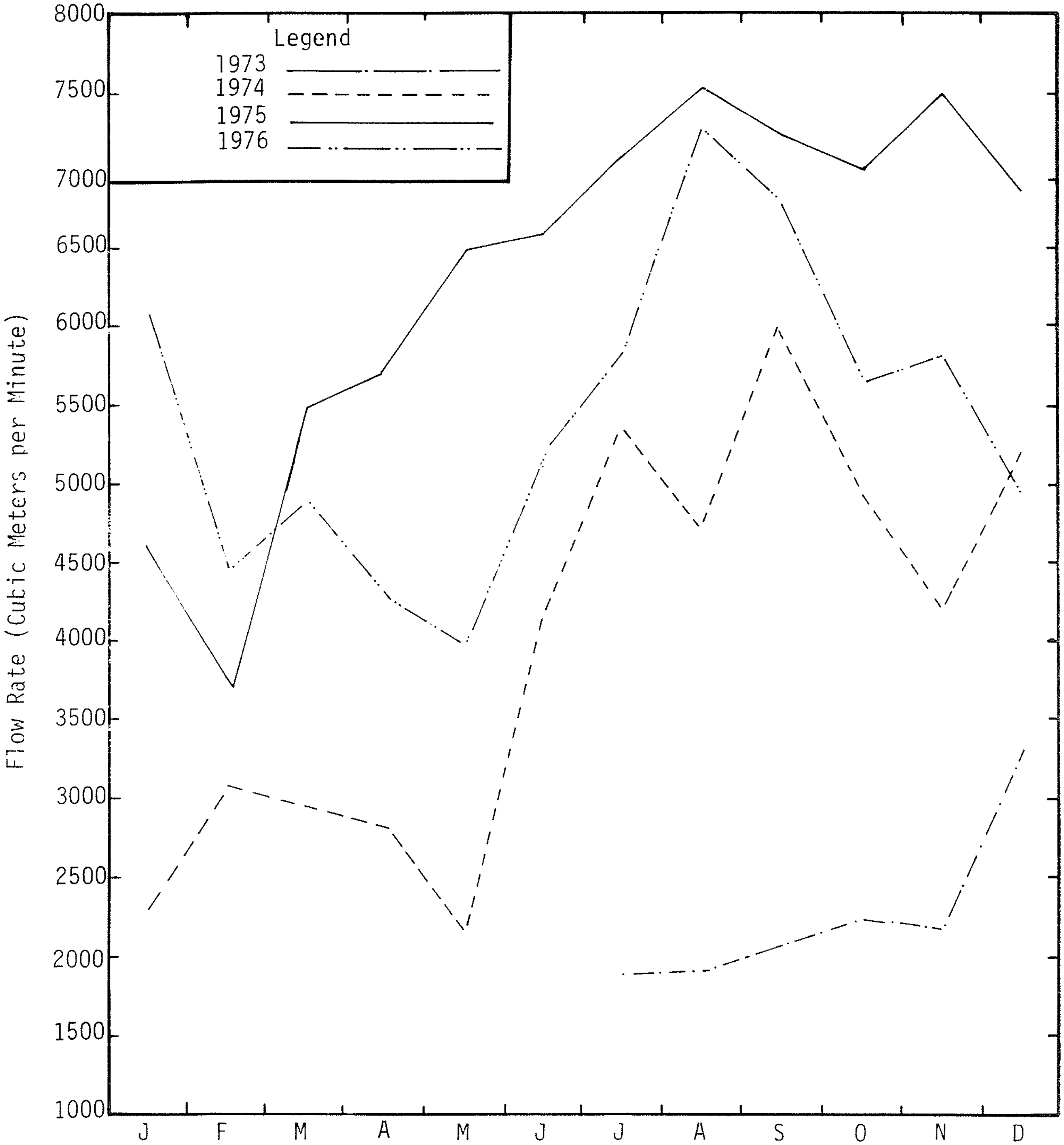
Figure: **2-28**



Condenser Cooling Water Flow Rates for
Oconee Nuclear Station
Figure: **2-29**

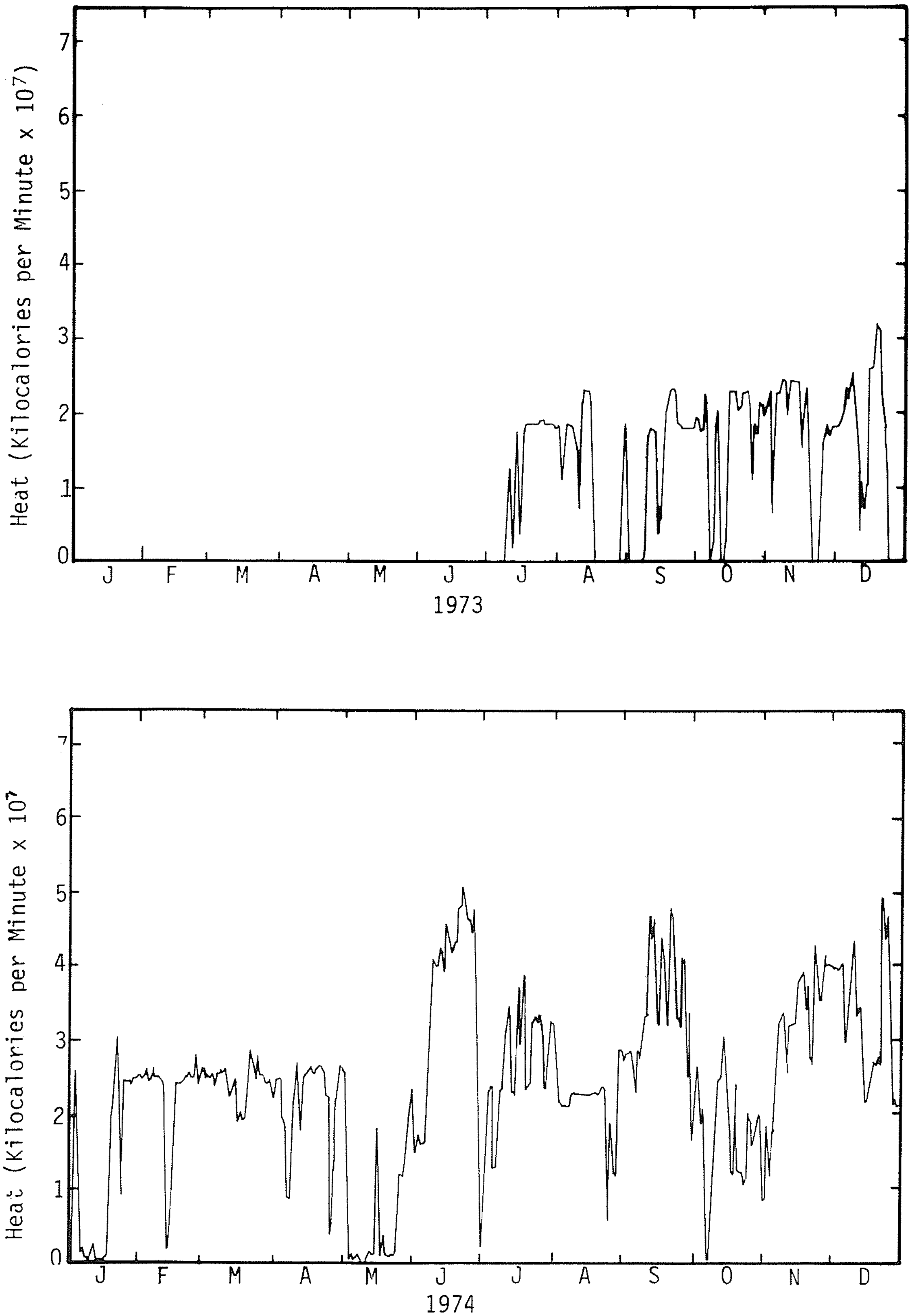


Condenser Cooling Water Flow Rates for
Oconee Nuclear Station
Figure: 2-30



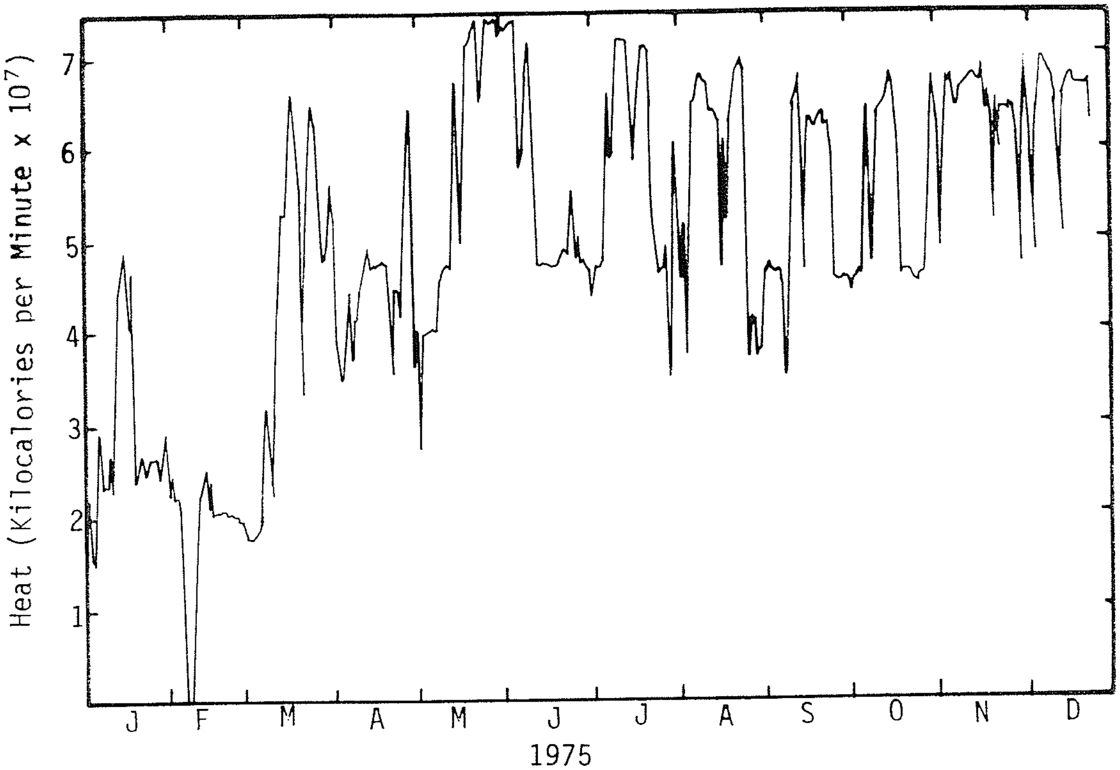
Condenser Cooling Water Flow Rates for Oconee Nuclear Station (Mean of the Daily Average)

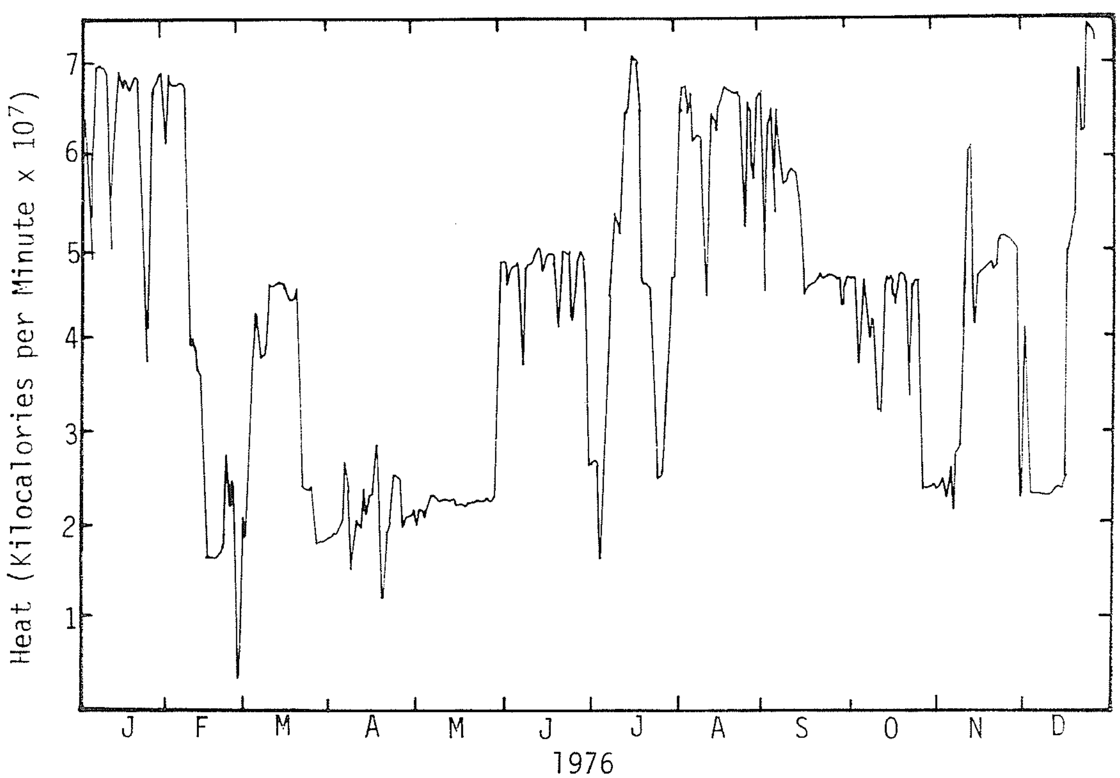
FIGURE:2-31



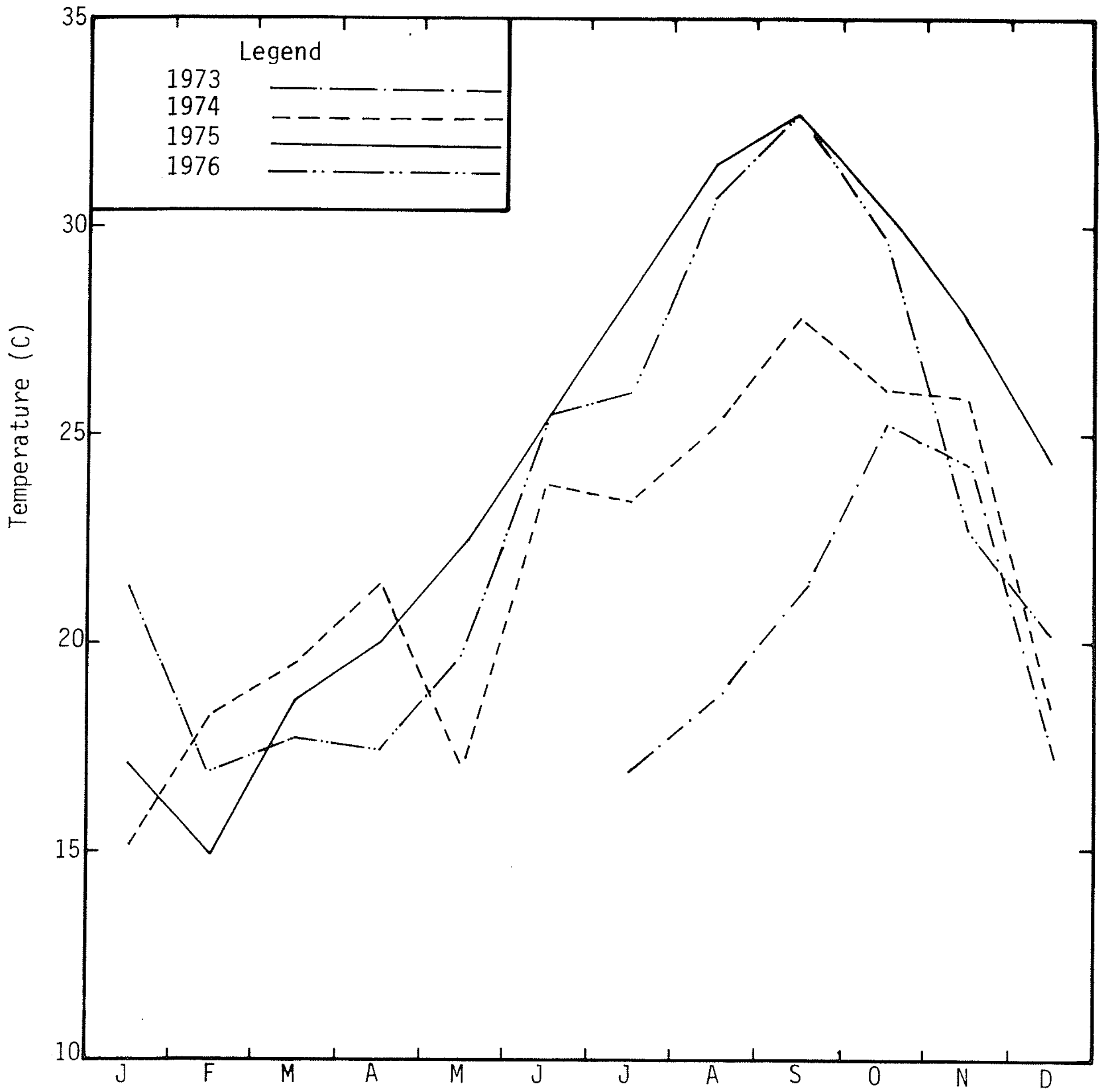
Heat Rejection Rates by Oconee Nuclear Station

Figure: 2-32

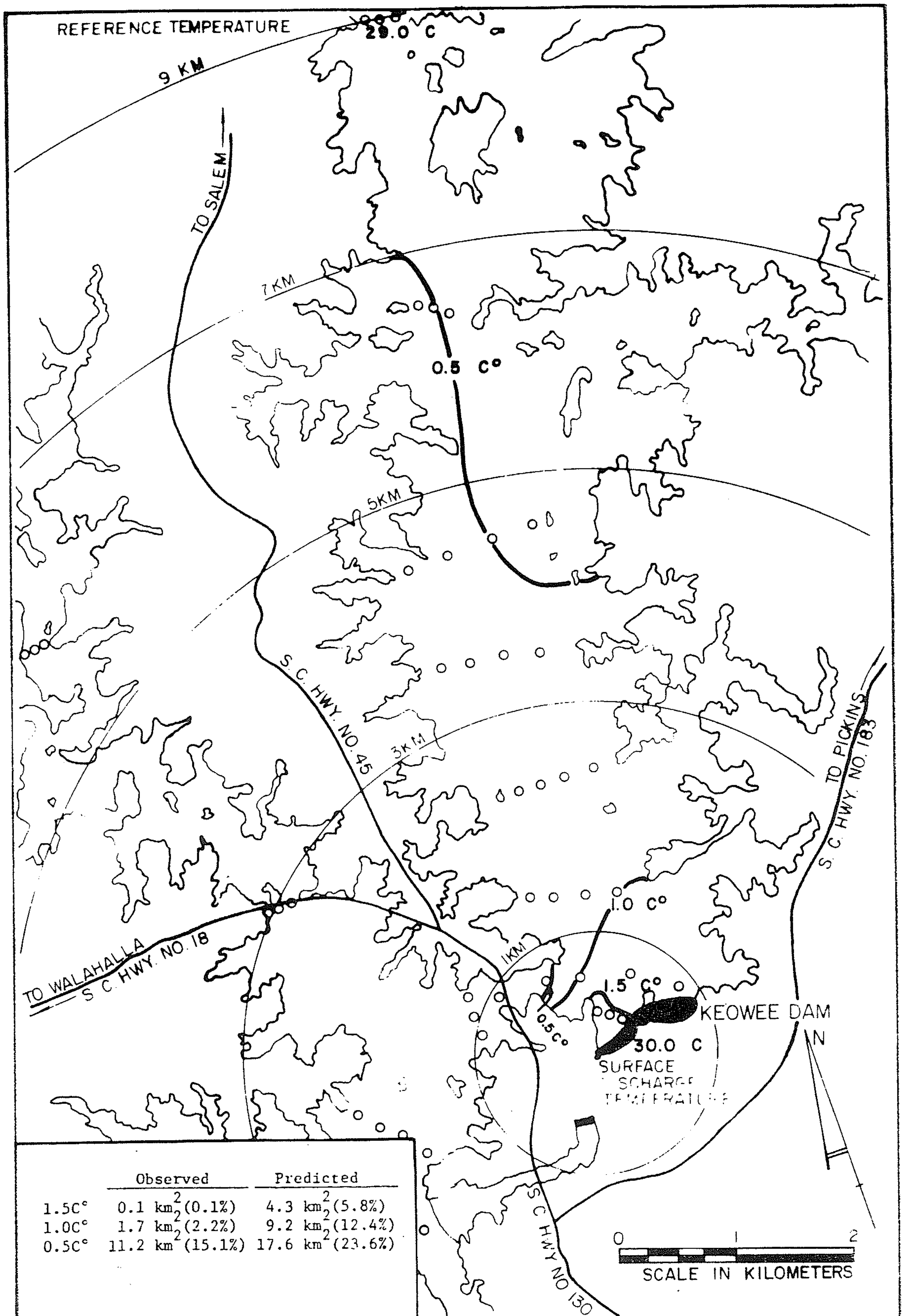




Heat Rejection Rates by Oconee Nuclear Station
Figure: 2-33



Monthly Mean of the Daily Average Outlet Temperatures
Figure:2-34

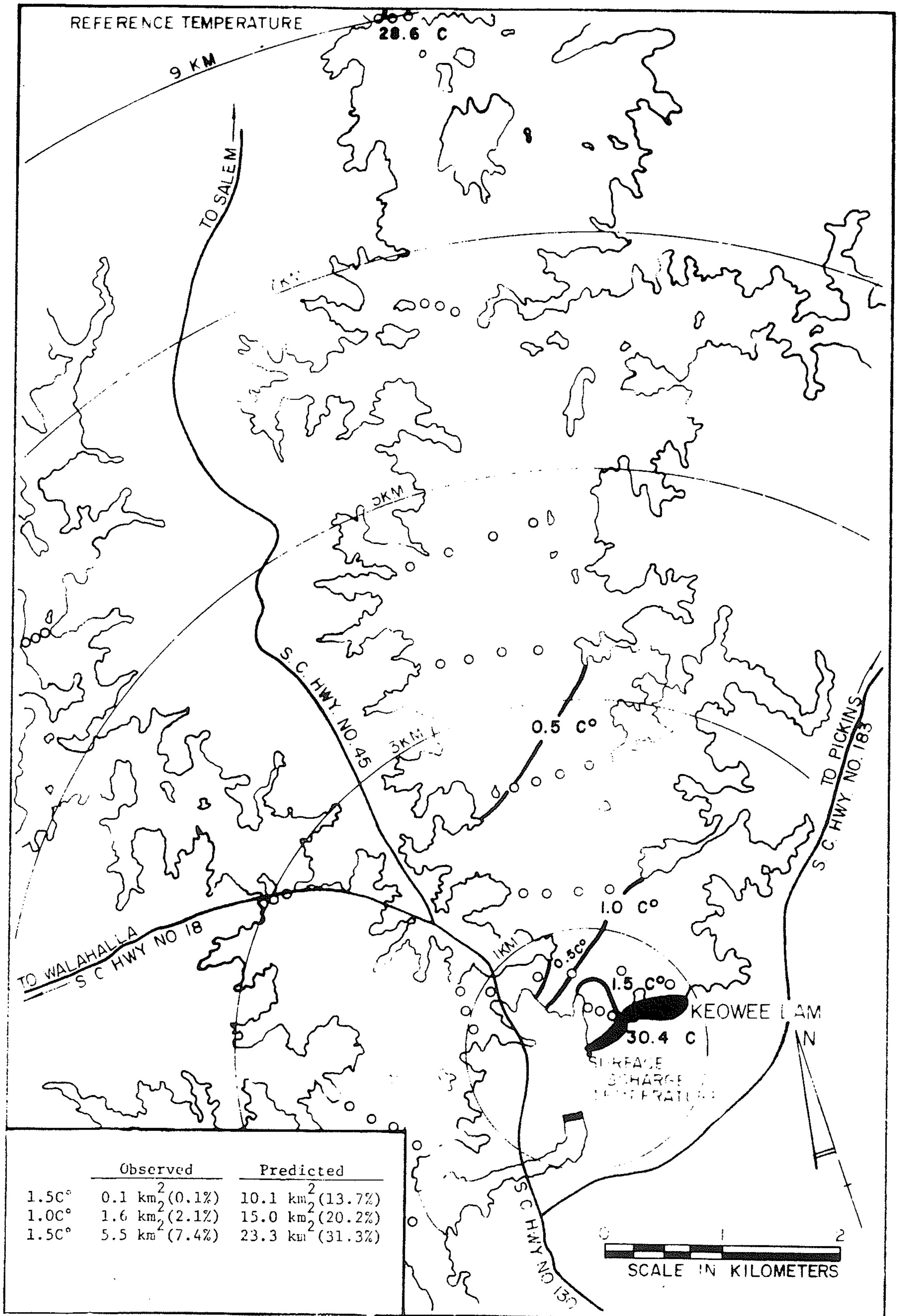


	Observed	Predicted
1.5C°	0.1 km^2 (0.1%)	4.3 km^2 (5.8%)
1.0C°	1.7 km^2 (2.2%)	9.2 km^2 (12.4%)
0.5C°	11.2 km^2 (15.1%)	17.6 km^2 (23.6%)

Date: 8/13/75

Oconee Nuclear Station
Plume Mapping Study
C° Above Reference

Figure: 2-35

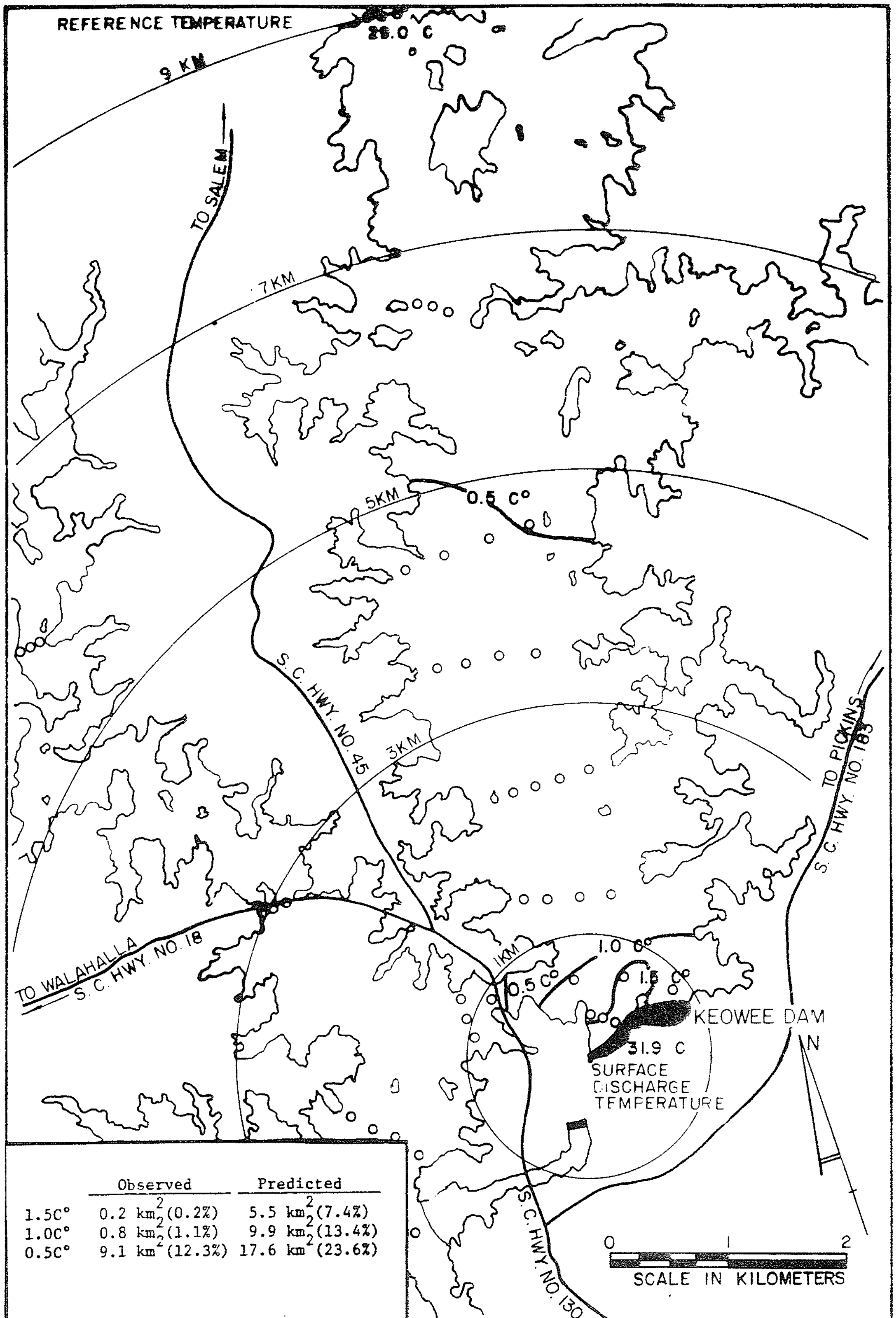


	Observed	Predicted
1.5C°	0.1 km^2 (0.1%)	10.1 km^2 (13.7%)
1.0C°	1.6 km^2 (2.1%)	15.0 km^2 (20.2%)
1.5C°	5.5 km^2 (7.4%)	23.3 km^2 (31.3%)

Date: 8/14/75

Oconee Nuclear Station
Plume Mapping Study
C° Above Reference

Figure: 2-36

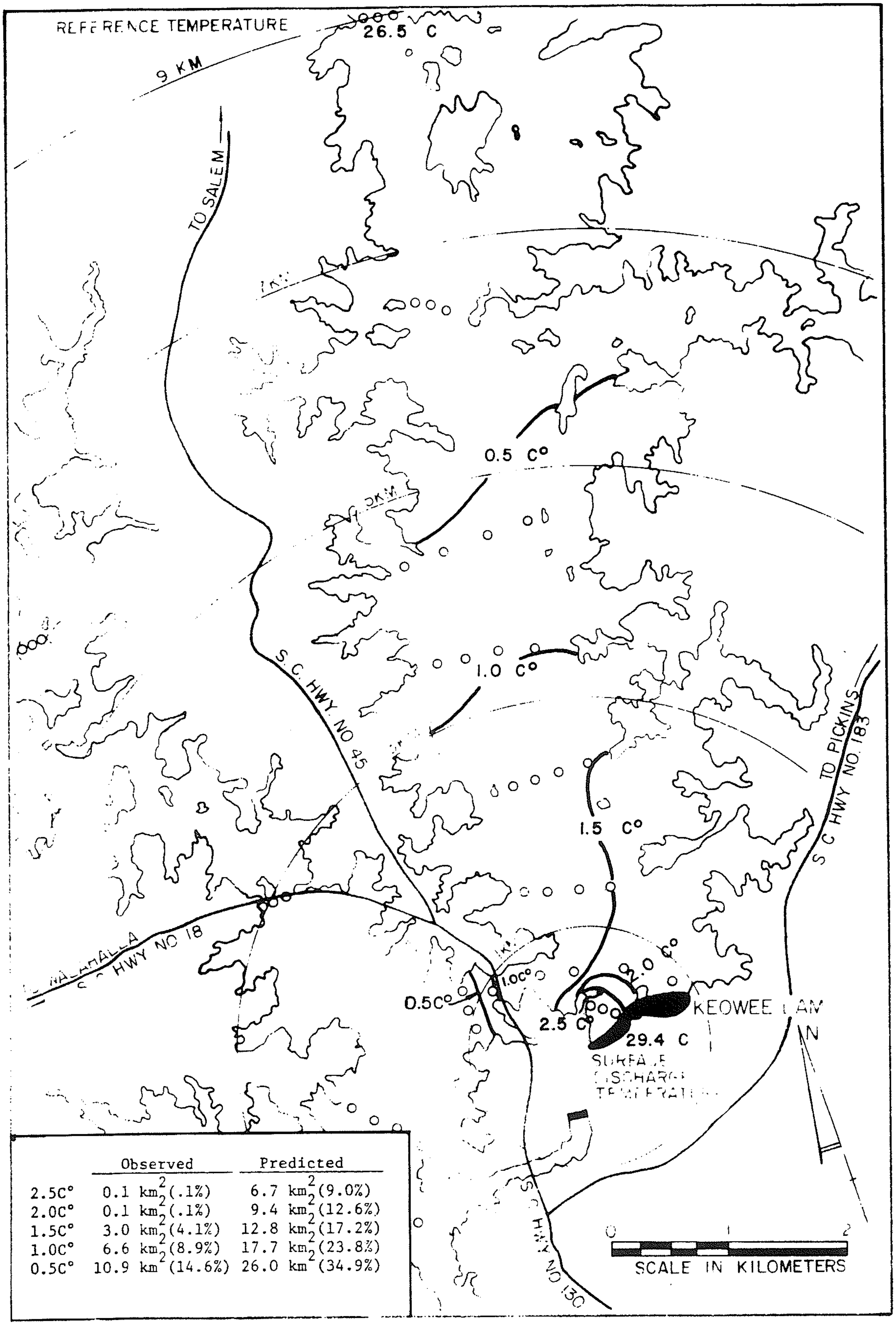


	Observed	Predicted
1.5C°	0.2 km^2 (0.2%)	5.5 km^2 (7.4%)
1.0C°	0.8 km^2 (1.1%)	9.9 km^2 (13.4%)
0.5C°	9.1 km^2 (12.3%)	17.6 km^2 (23.6%)

Date: 9/10/75

Oconee Nuclear Station
Plume Mapping Study
C° Above Reference

Figure: 2-37

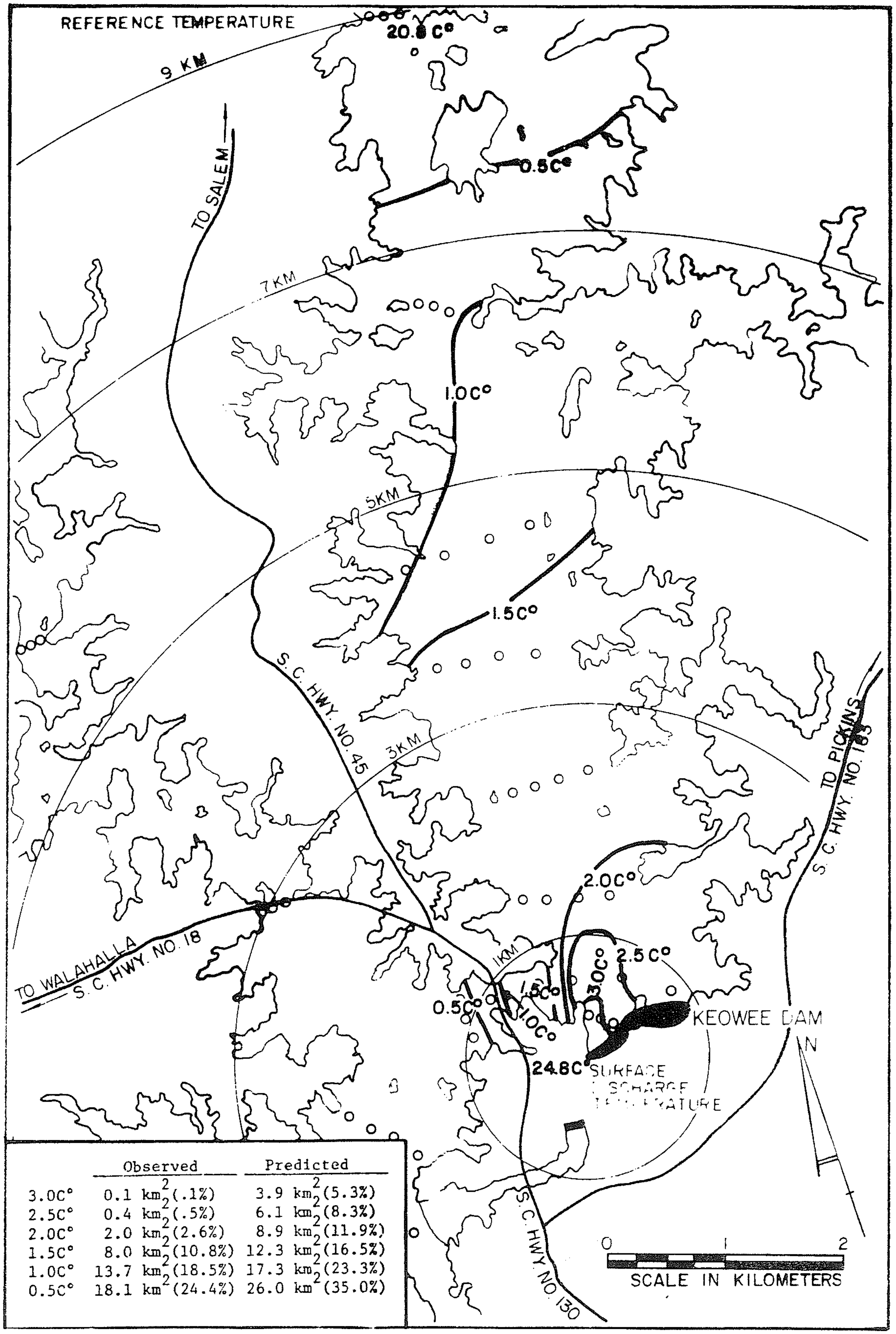


	Observed	Predicted
2.5C°	0.1 km^2(.1%)	6.7 km^2(9.0%)
2.0C°	0.1 km^2(.1%)	9.4 km^2(12.6%)
1.5C°	3.0 km^2(4.1%)	12.8 km^2(17.2%)
1.0C°	6.6 km^2(8.9%)	17.7 km^2(23.8%)
0.5C°	10.9 km^2(14.6%)	26.0 km^2(34.9%)

Date: 9/24/75

Oconee Nuclear Station
Plume Mapping Study
C° Above Reference

Figure: 2-38

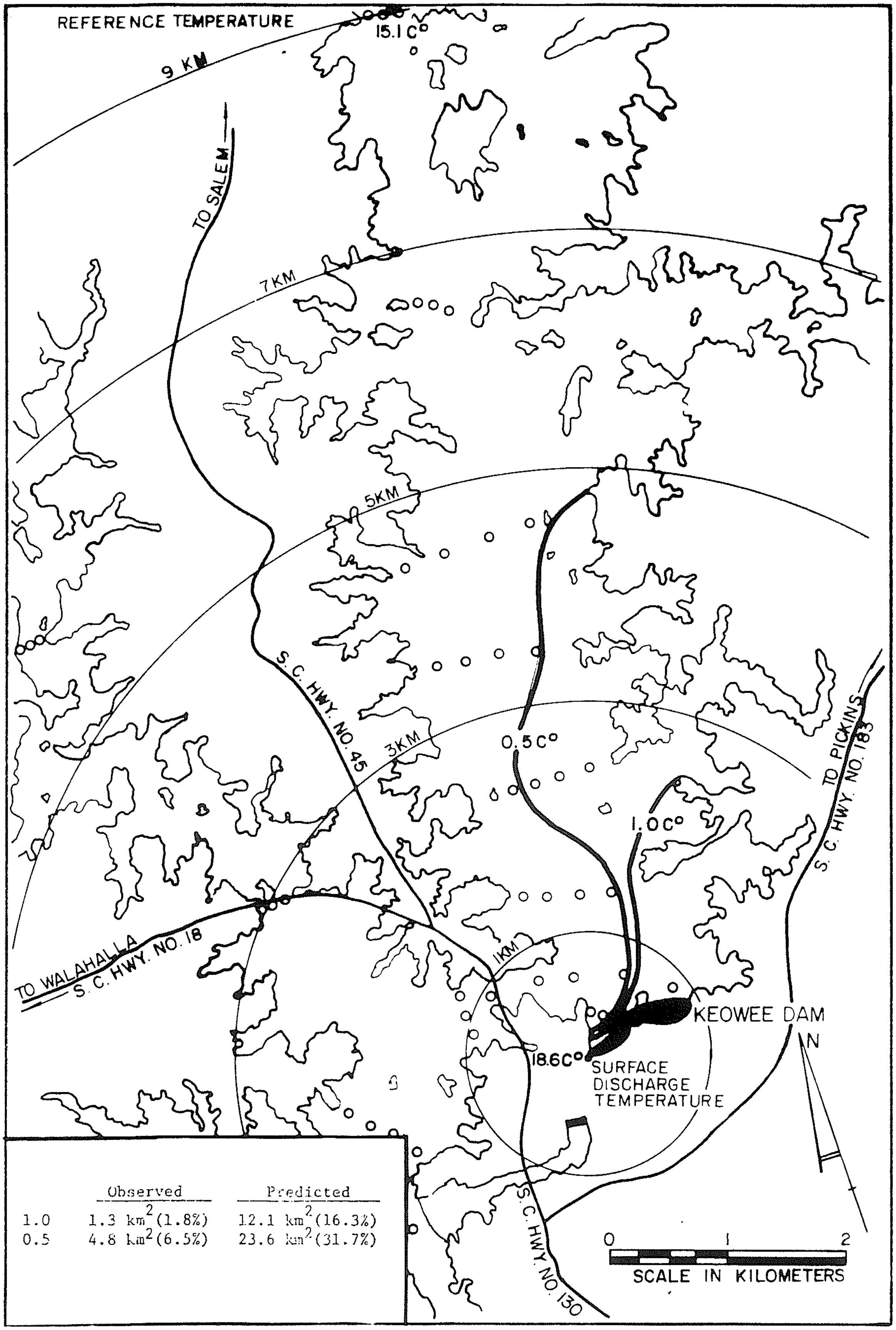


	Observed	Predicted
3.0C°	0.1 km^2 (.1%)	3.9 km^2 (5.3%)
2.5C°	0.4 km^2 (.5%)	6.1 km^2 (8.3%)
2.0C°	2.0 km^2 (2.6%)	8.9 km^2 (11.9%)
1.5C°	8.0 km^2 (10.8%)	12.3 km^2 (16.5%)
1.0C°	13.7 km^2 (18.5%)	17.3 km^2 (23.3%)
0.5C°	18.1 km^2 (24.4%)	26.0 km^2 (35.0%)

Date: 11/19/75

Oconee Nuclear Station
Plume Mapping Study
C° Above Reference

Figure: 2-39

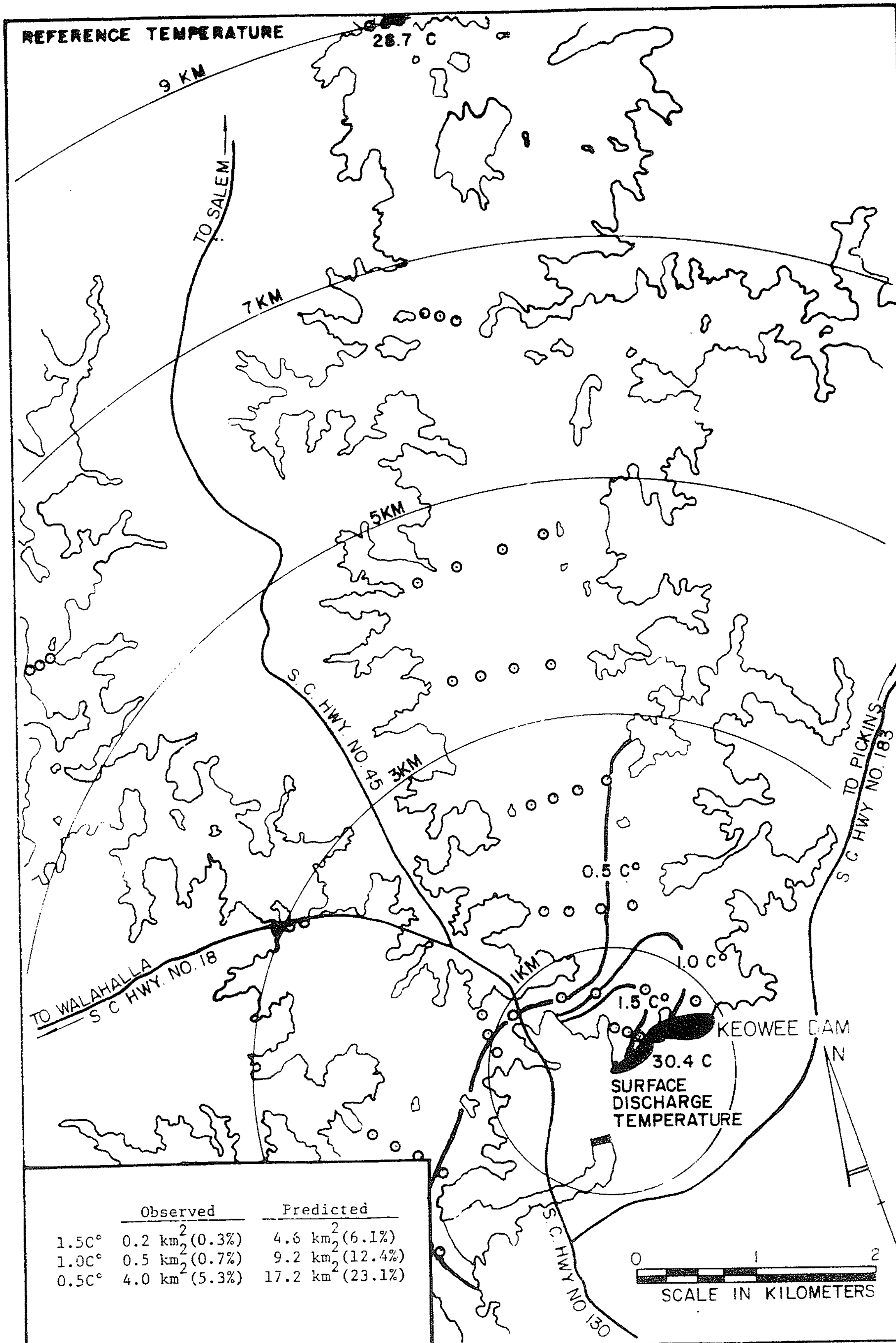


	Observed	Predicted
1.0	1.3 km^2(1.8%)	12.1 km^2(16.3%)
0.5	4.8 km^2(6.5%)	23.6 km^2(31.7%)

Date: 3/11/76

Oconee Nuclear Station
Plume Mapping Study
C° Above Reference

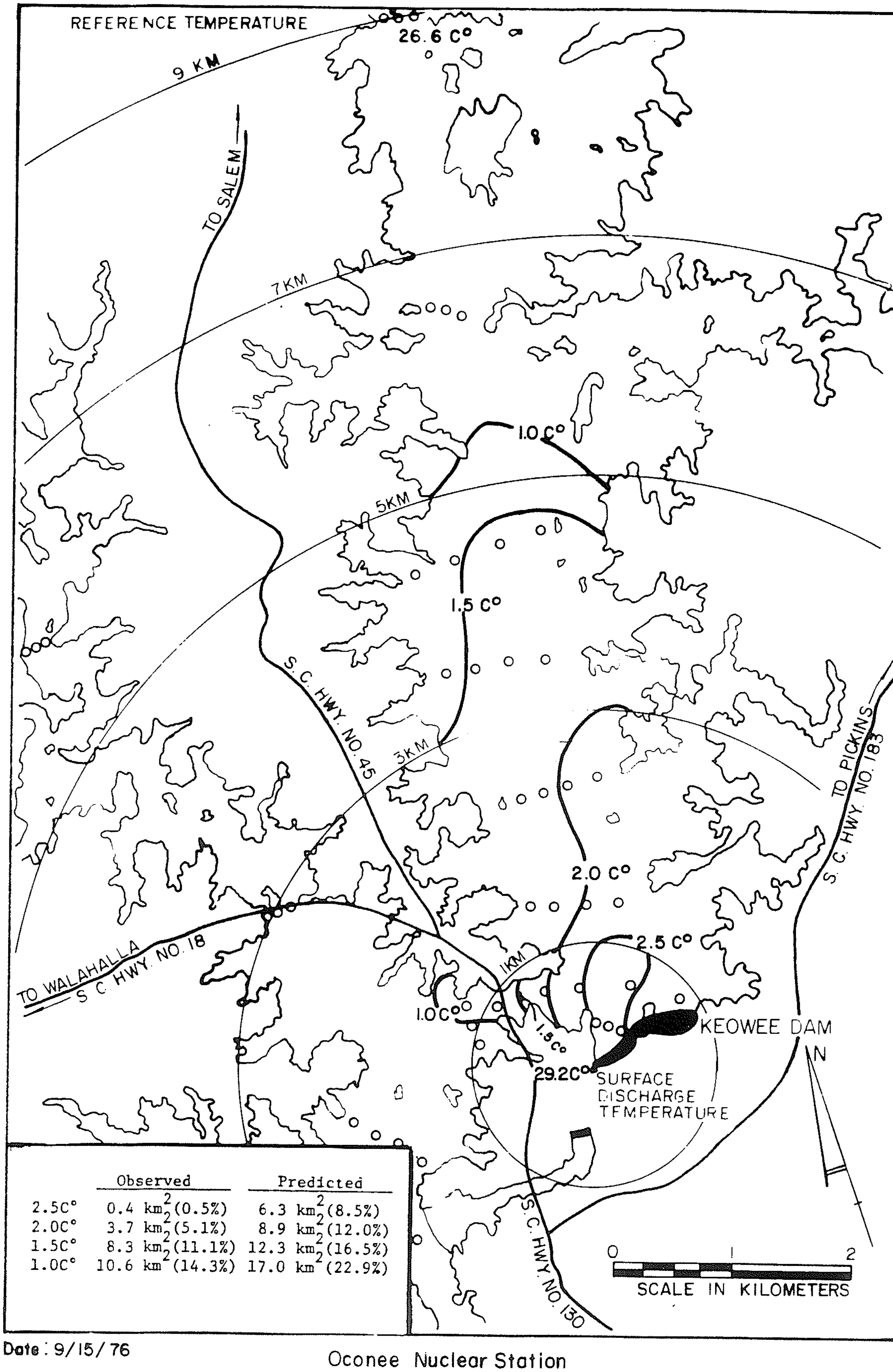
Figure: 2-40



Date: 9/1/76

Oconee Nuclear Station
Plume Mapping Study
C° Above Reference

Figure: 2-41

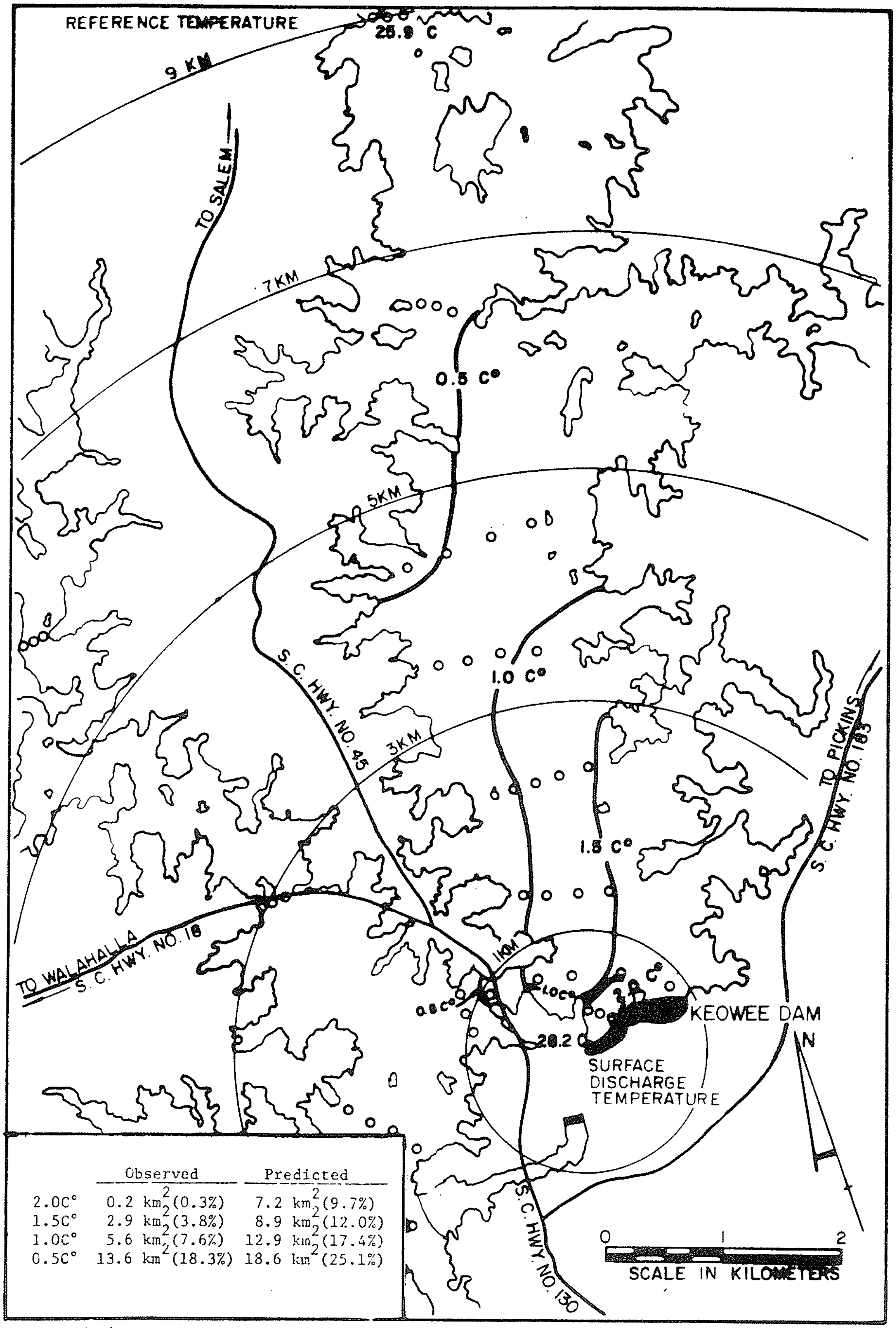


	Observed	Predicted
2.5C°	0.4 km^2(0.5%)	6.3 km^2(8.5%)
2.0C°	3.7 km^2(5.1%)	8.9 km^2(12.0%)
1.5C°	8.3 km^2(11.1%)	12.3 km^2(16.5%)
1.0C°	10.6 km^2(14.3%)	17.0 km^2(22.9%)

Date: 9/15/76

Oconee Nuclear Station
Plume Mapping Study
C° Above Reference

Figure: 2-42

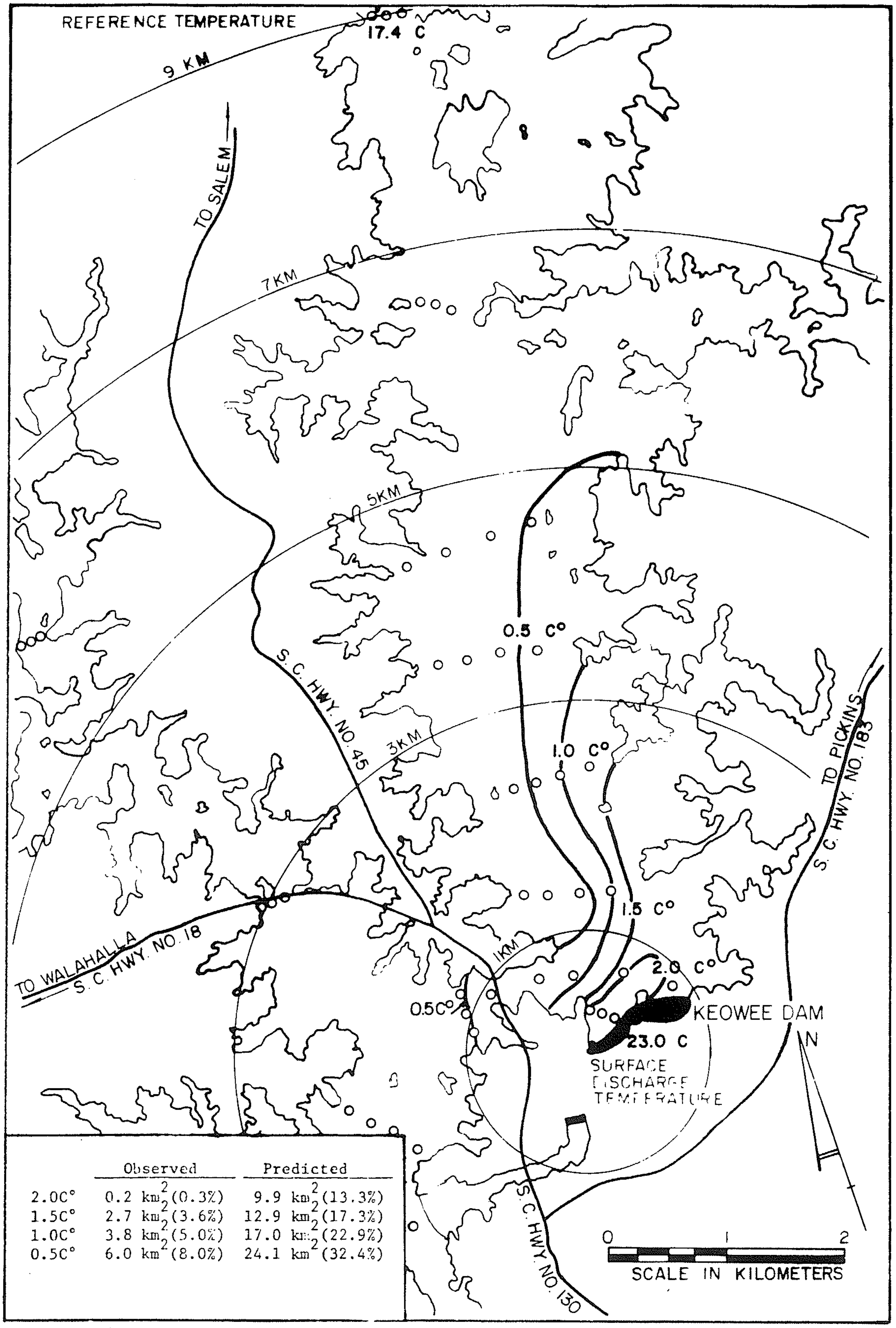


	Observed	Predicted
2.0C°	0.2 km^2 (0.3%)	7.2 km^2 (9.7%)
1.5C°	2.9 km^2 (3.8%)	8.9 km^2 (12.0%)
1.0C°	5.6 km^2 (7.6%)	12.9 km^2 (17.4%)
0.5C°	13.6 km^2 (18.3%)	18.6 km^2 (25.1%)

Date: 10/6/76

Oconee Nuclear Station
Plume Mapping Study
C° Above Reference

Figure: 2-43

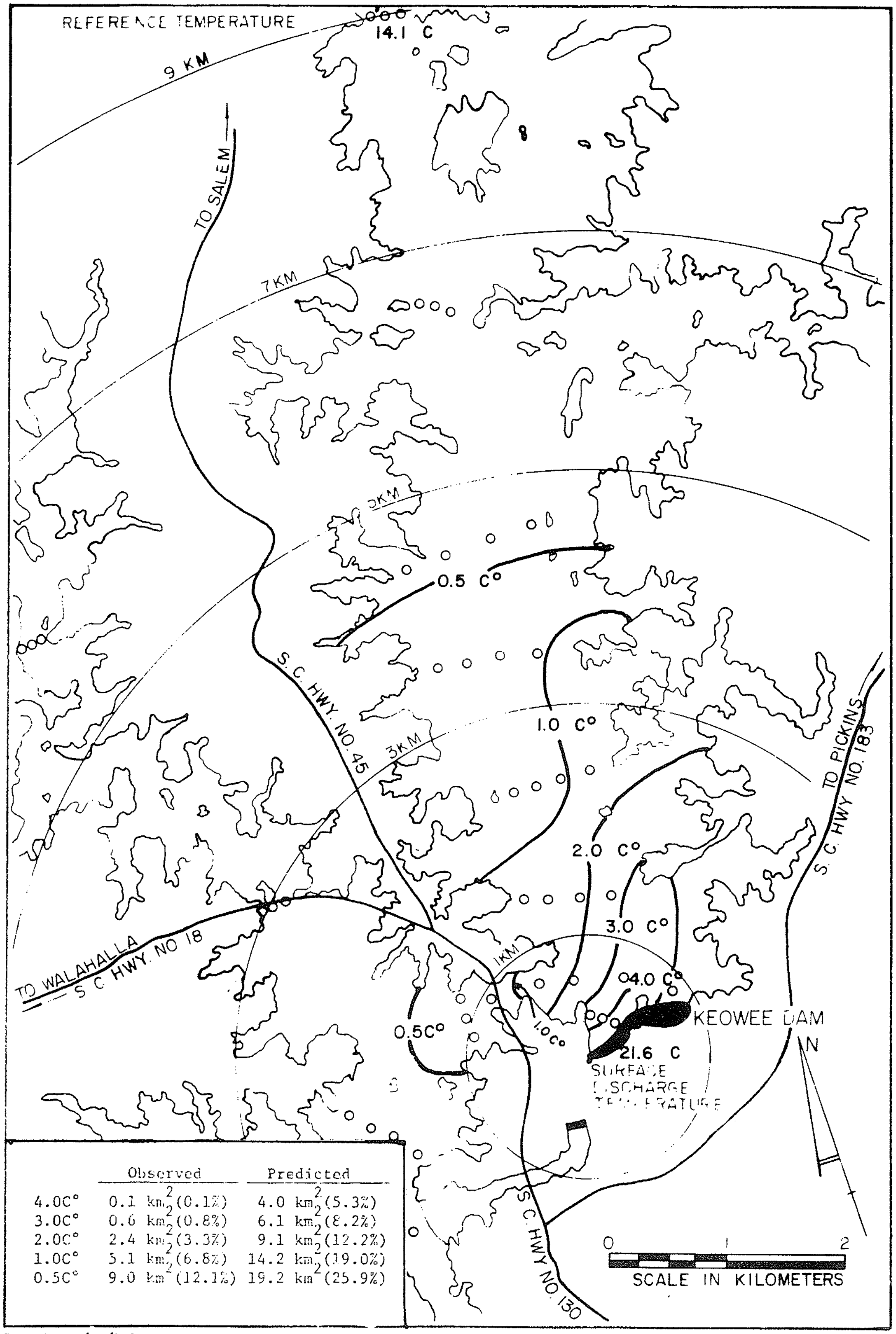


	Observed	Predicted
2.0C°	0.2 km^2 (0.3%)	9.9 km^2 (13.3%)
1.5C°	2.7 km^2 (3.6%)	12.9 km^2 (17.3%)
1.0C°	3.8 km^2 (5.0%)	17.0 km^2 (22.9%)
0.5C°	6.0 km^2 (8.0%)	24.1 km^2 (32.4%)

Date: 11/18/76

Oconee Nuclear Station
Plume Mapping Study
C° Above Reference

Figure: 2-44

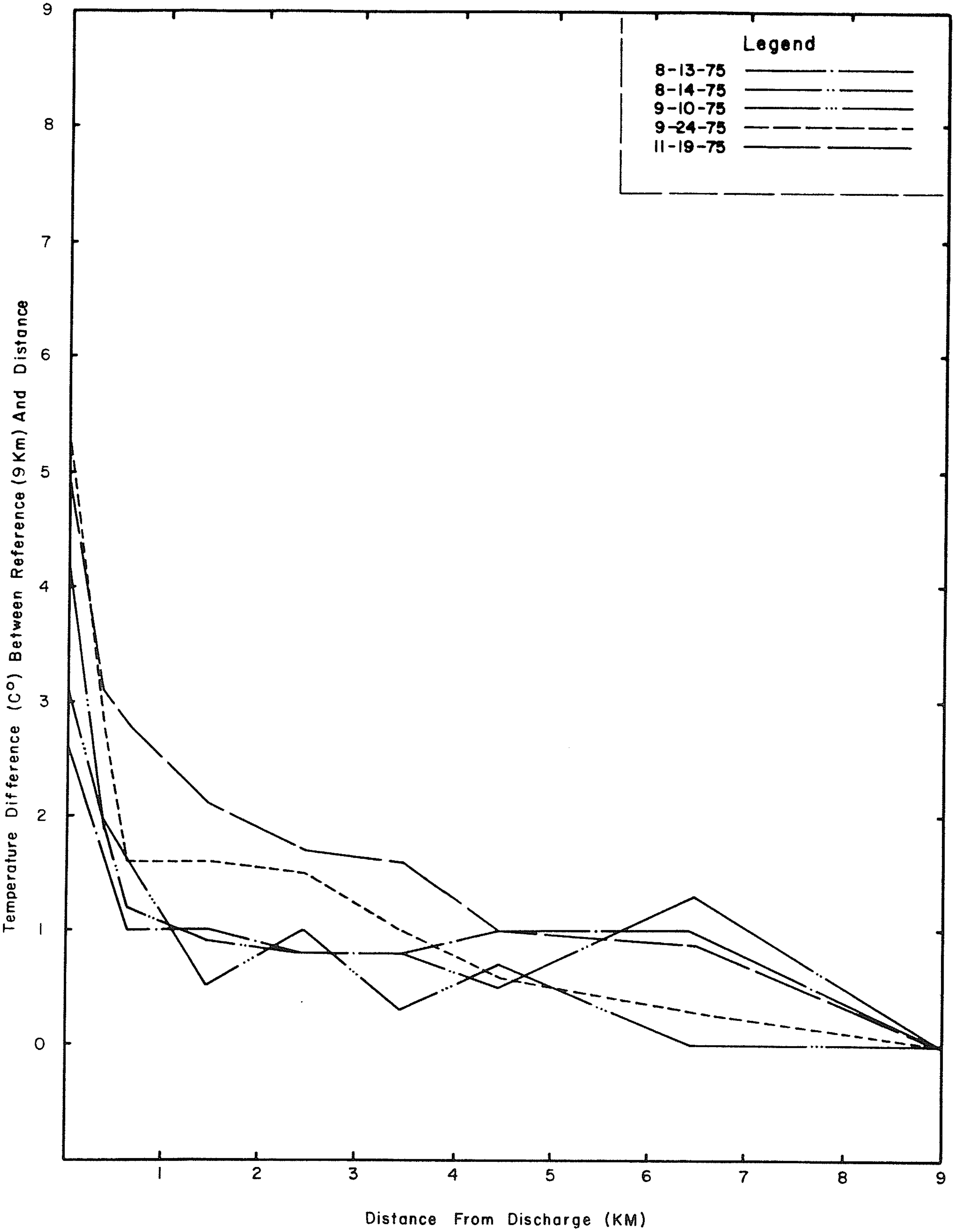


	Observed	Predicted
4.0C°	0.1 km^2 (0.1%)	4.0 km^2 (5.3%)
3.0C°	0.6 km^2 (0.8%)	6.1 km^2 (8.2%)
2.0C°	2.4 km^2 (3.3%)	9.1 km^2 (12.2%)
1.0C°	5.1 km^2 (6.8%)	14.2 km^2 (19.0%)
0.5C°	9.0 km^2 (12.1%)	19.2 km^2 (25.9%)

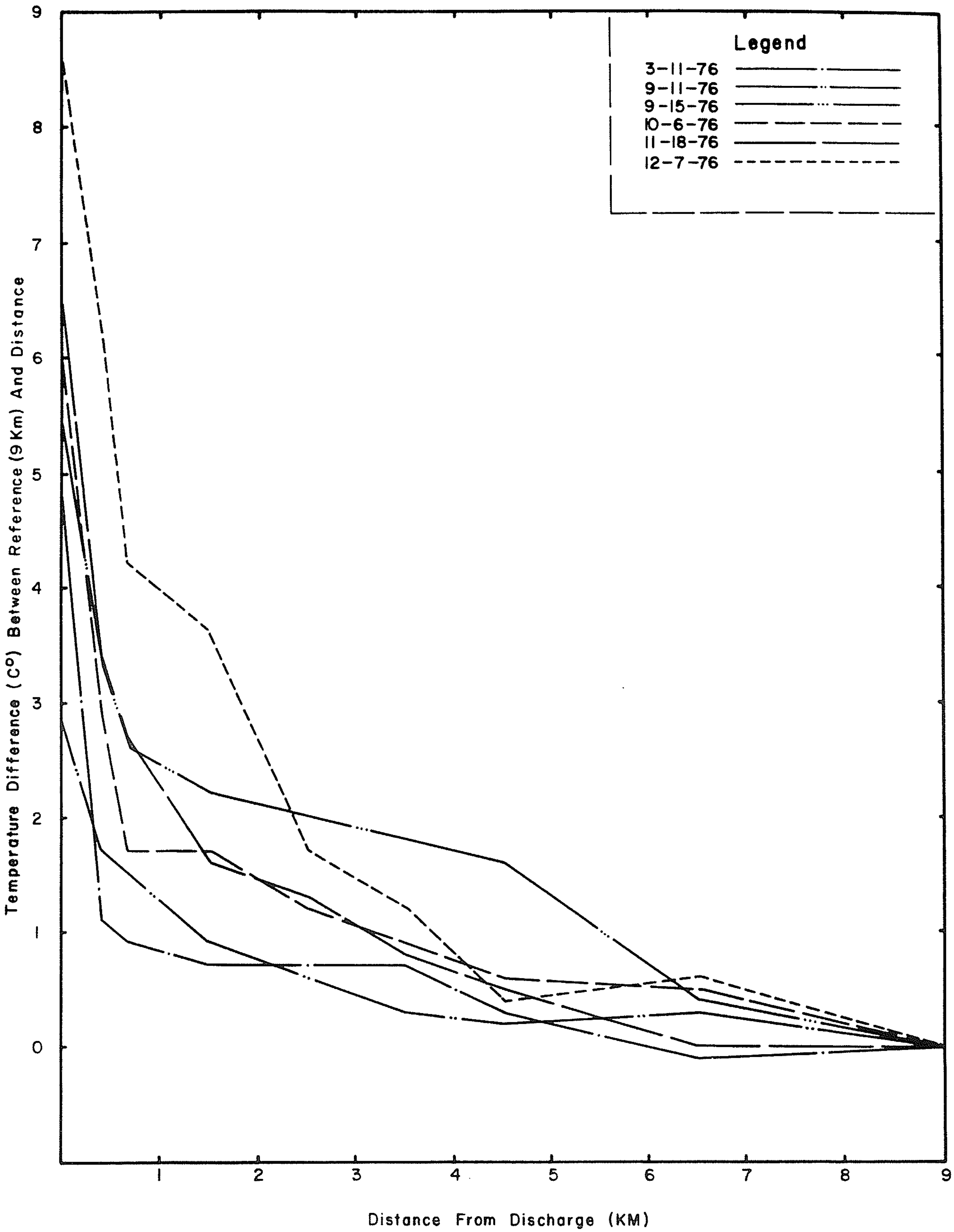
Date: 12/7/76

Oconee Nuclear Station
Plume Mapping Study
C° Above Reference

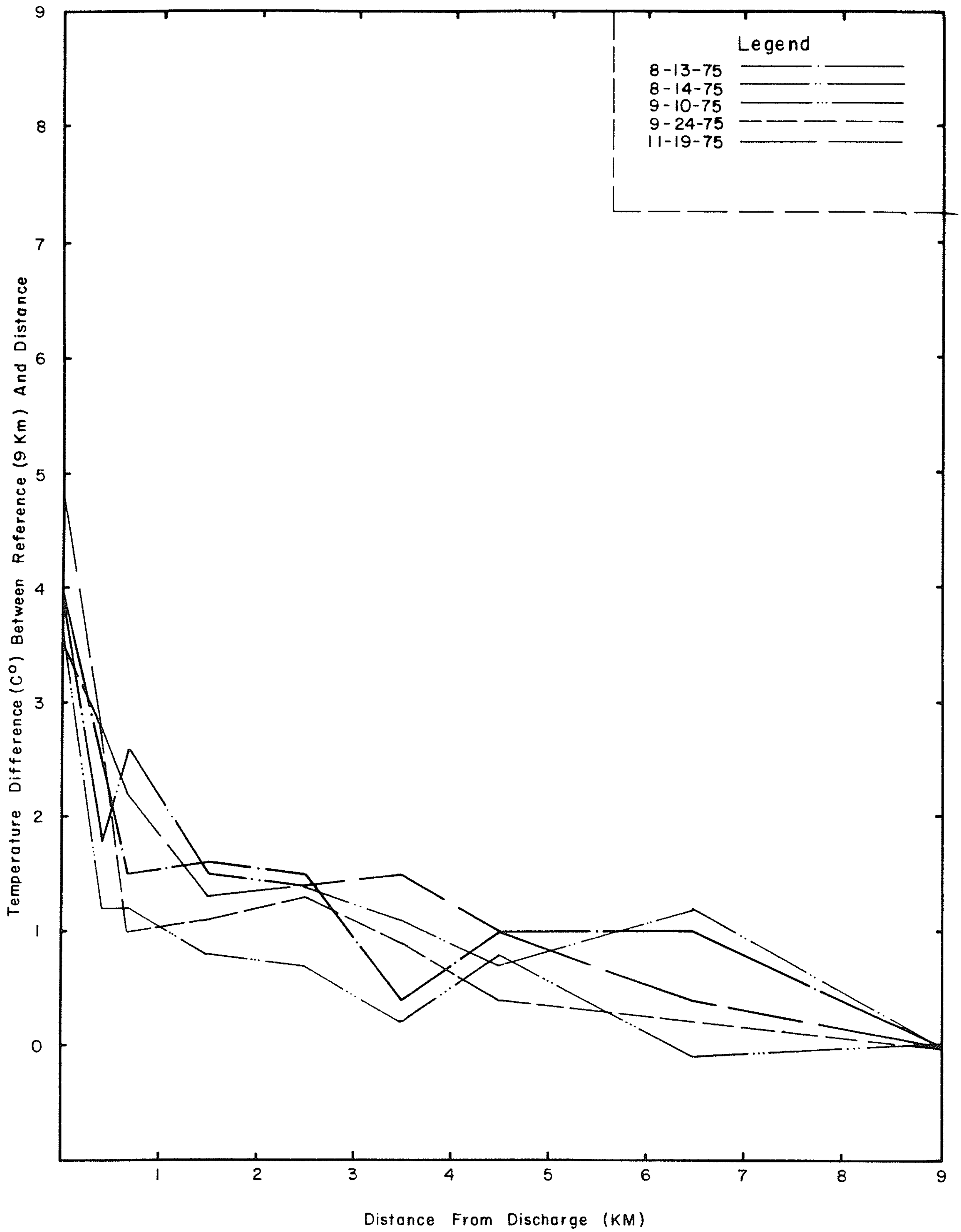
Figure: 2-45



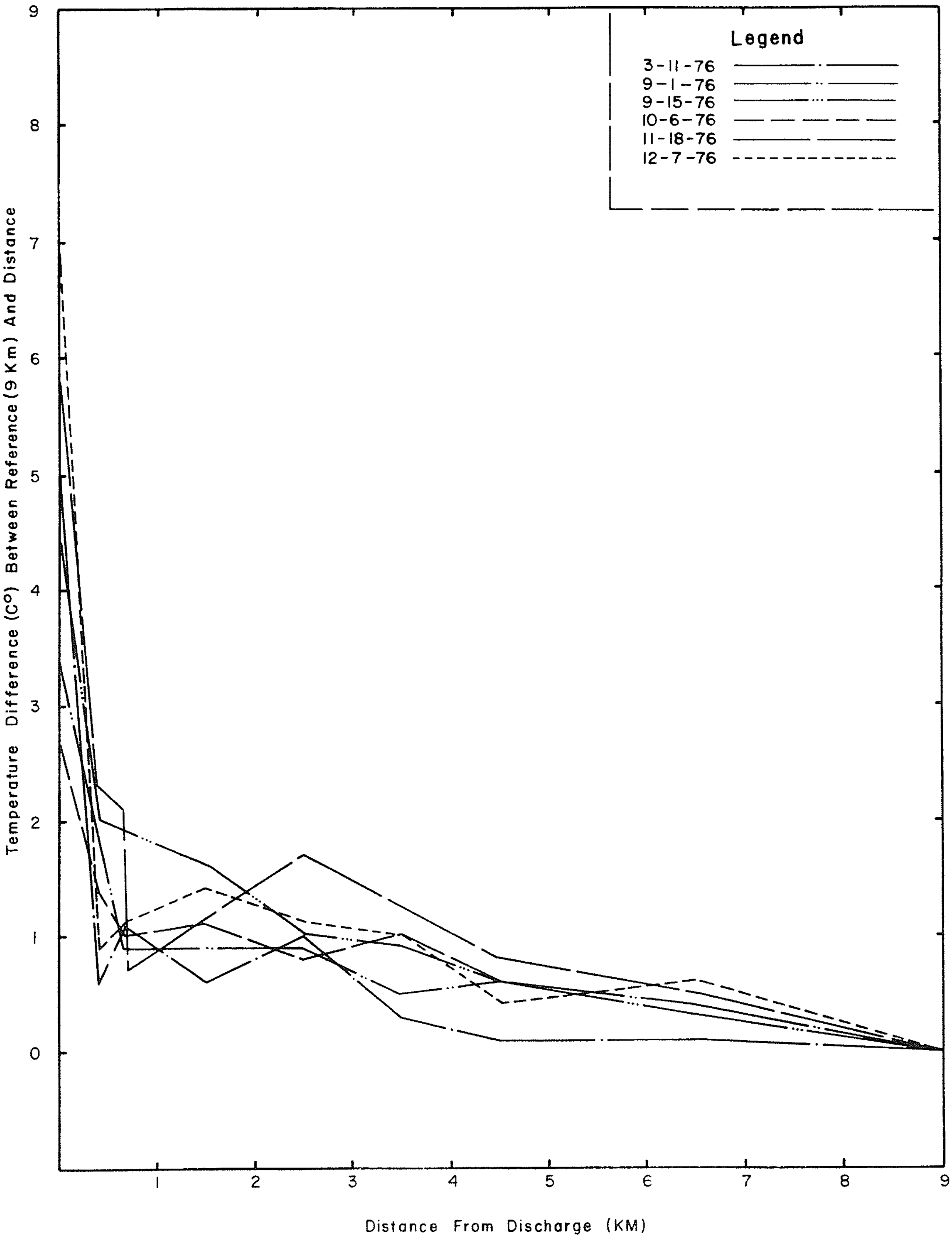
Centerline Decay For Plume Surveys
Conducted In 1975 (Surface 0.3m)
Figure :2-46



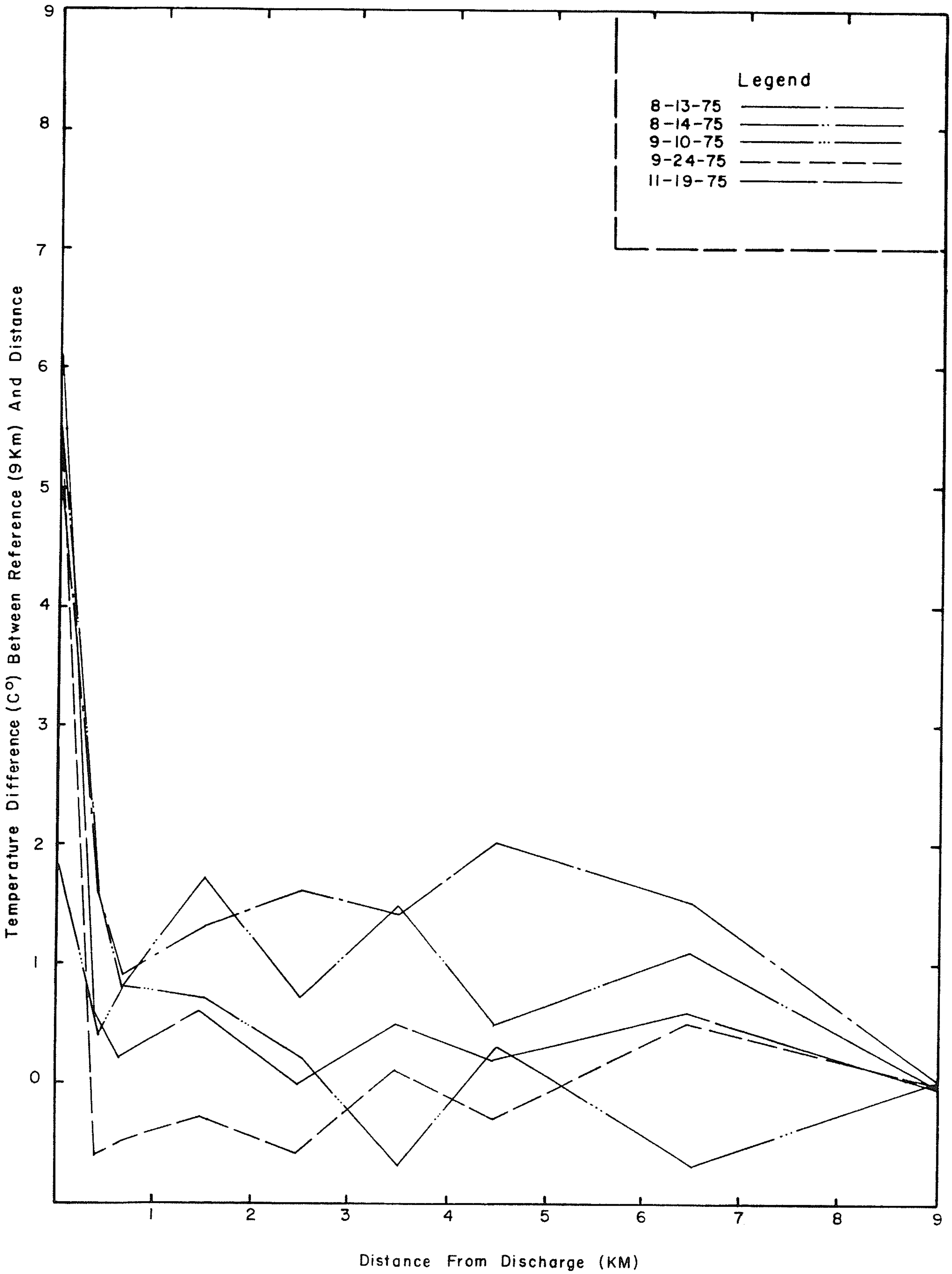
Centerline Decay For Plume Surveys
Conducted in 1976 (Surface 0.3m)
Figure 2-47



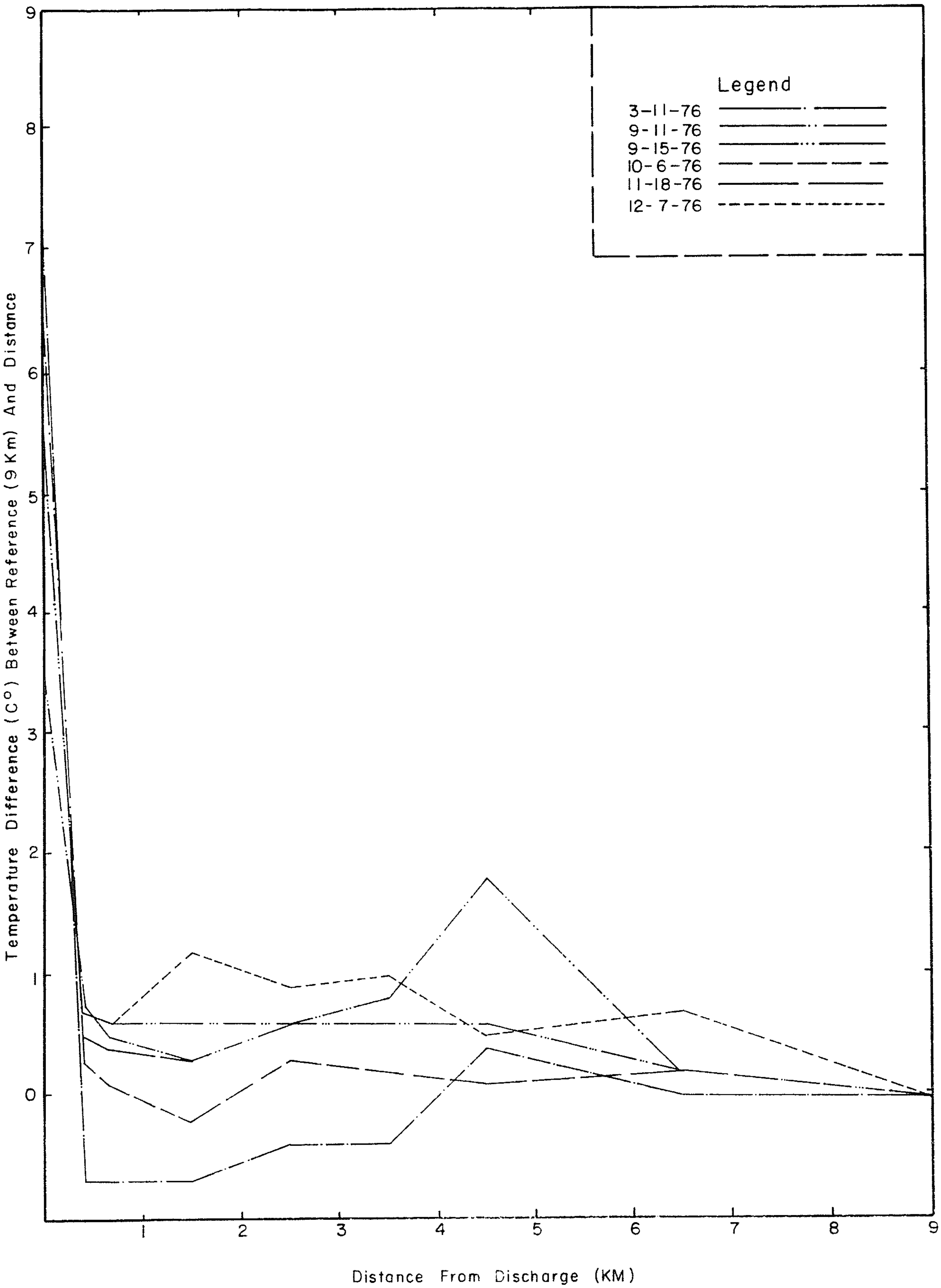
Centerline Decay For Plume Surveys Conducted In 1975 (5m Depth)
Figure :2-48



Centerline Decay For Plume Surveys
Conducted In 1976 (5m Depth)
Figure: 2-49



Centerline Decay For Plume Surveys
Conducted In 1975 (10m Depth)
Figure 2-50



Centerline Decay For Plume Surveys
Conducted in 1976 (10 m Depth)
Figure 2-51

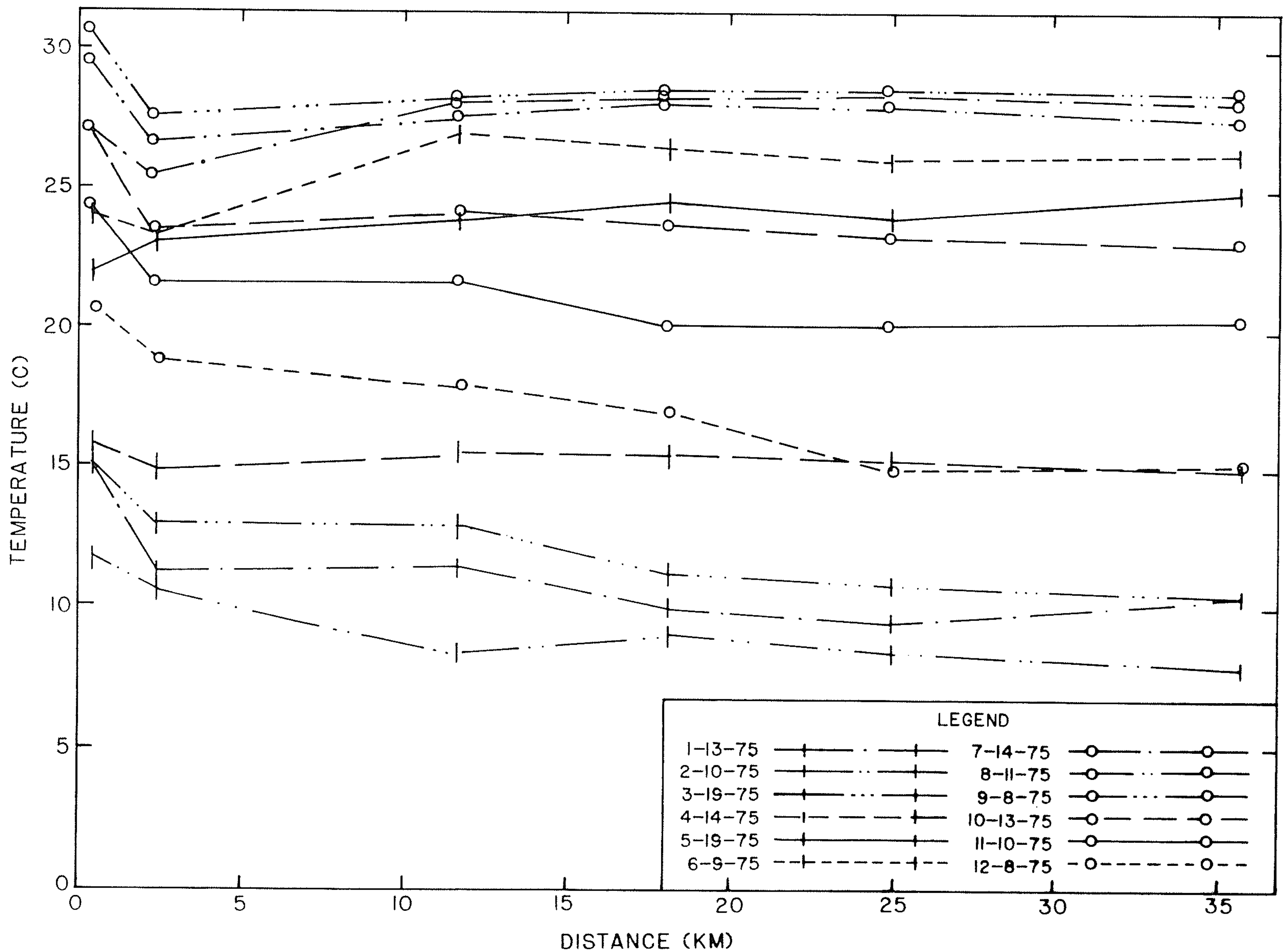


Figure: 2-52 **Lake Hartwell Surface Temperatures Versus Distance from Oconee Nuclear Station for 1975 (Locations 504.0, 605.0, 604.0, 603.0, 602.0, 601.0)**

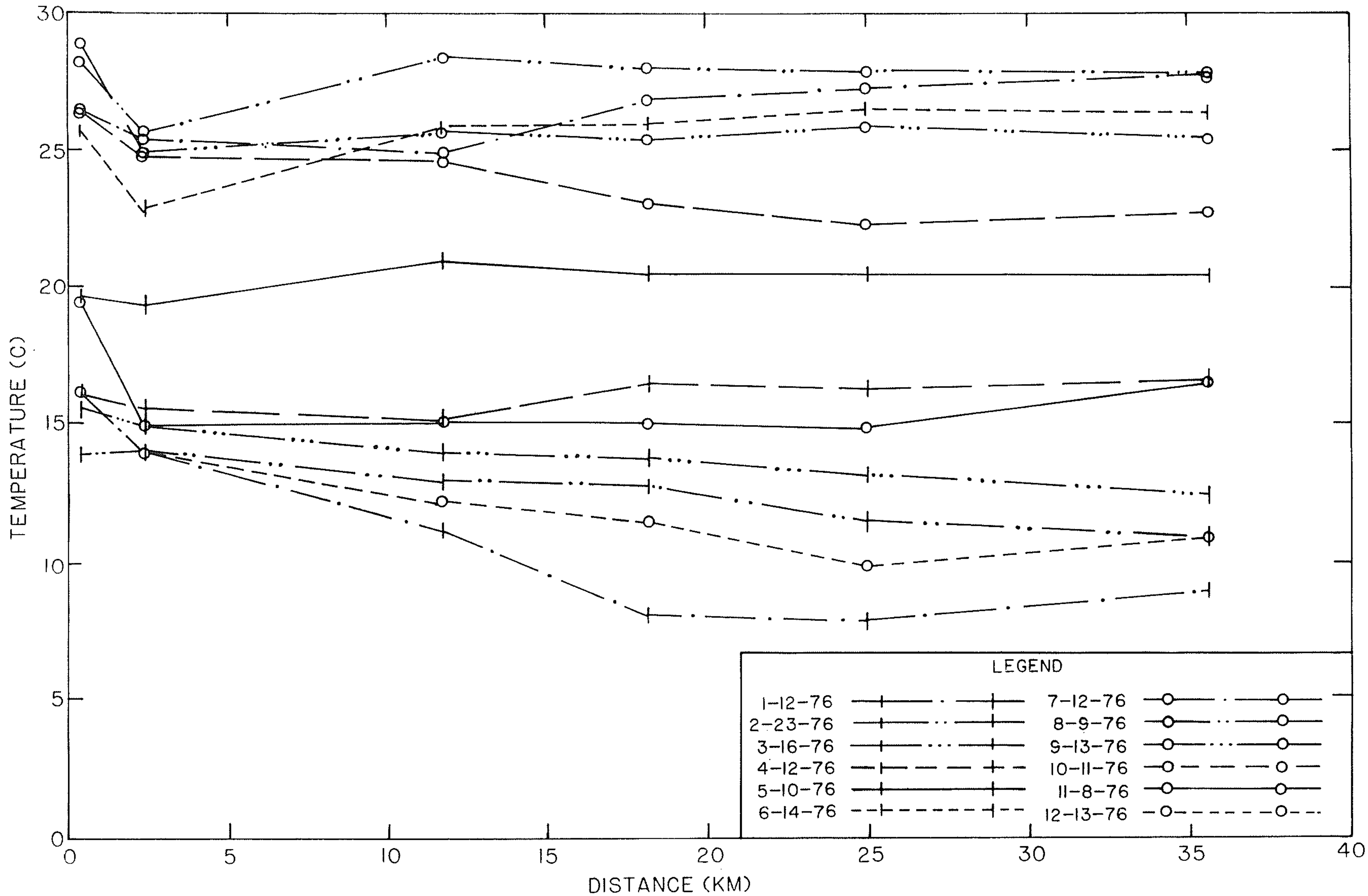
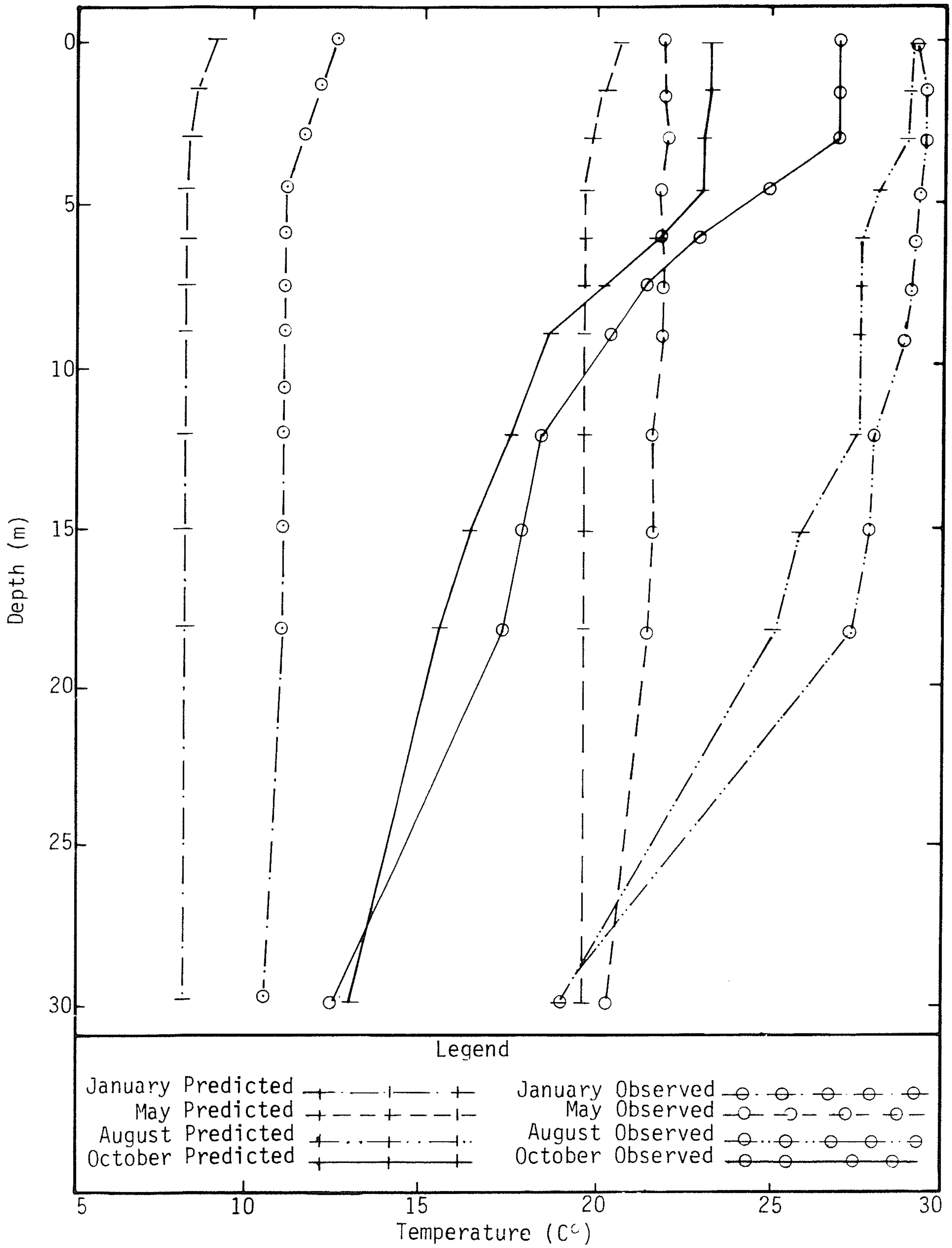
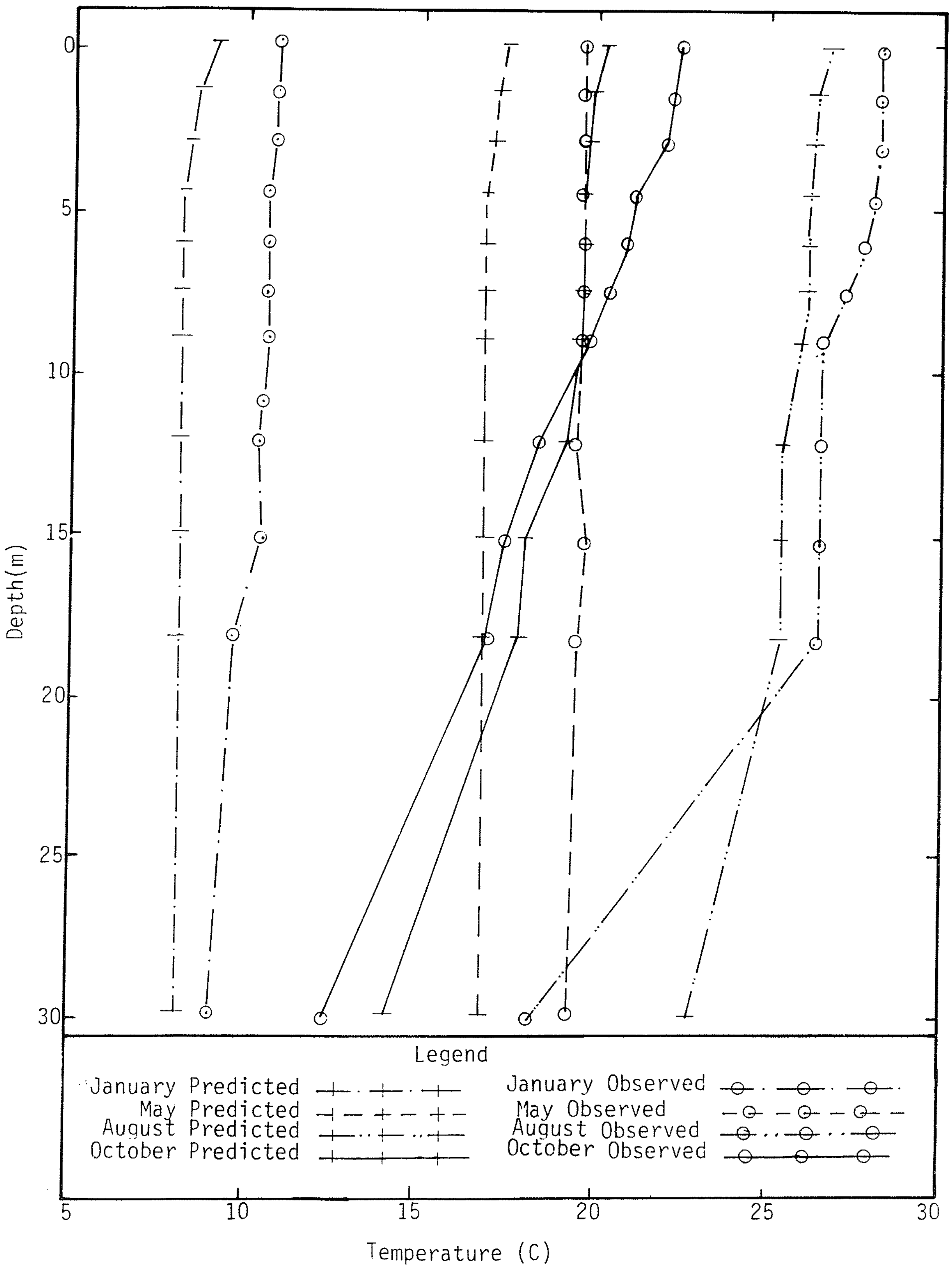


Figure: **2 - 53** Lake Hartwell Surface Temperatures Versus Distance from Oconee Nuclear Station for 1976 (Locations 504.0, 605.0, 604.0, 603.0, 602.0, 601.0)

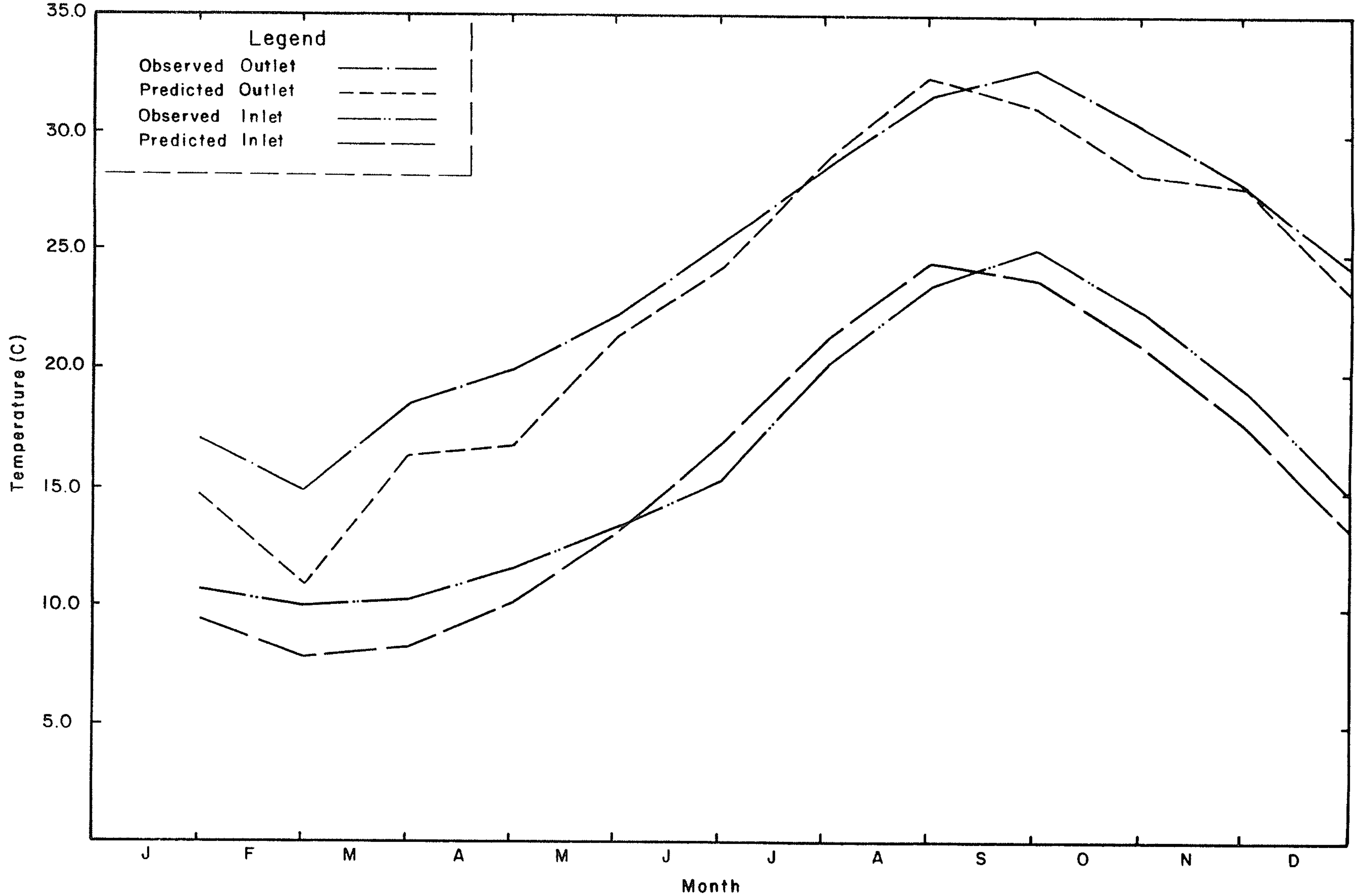


Observed and Predicted Temperatures at Location 502.0 for 1975

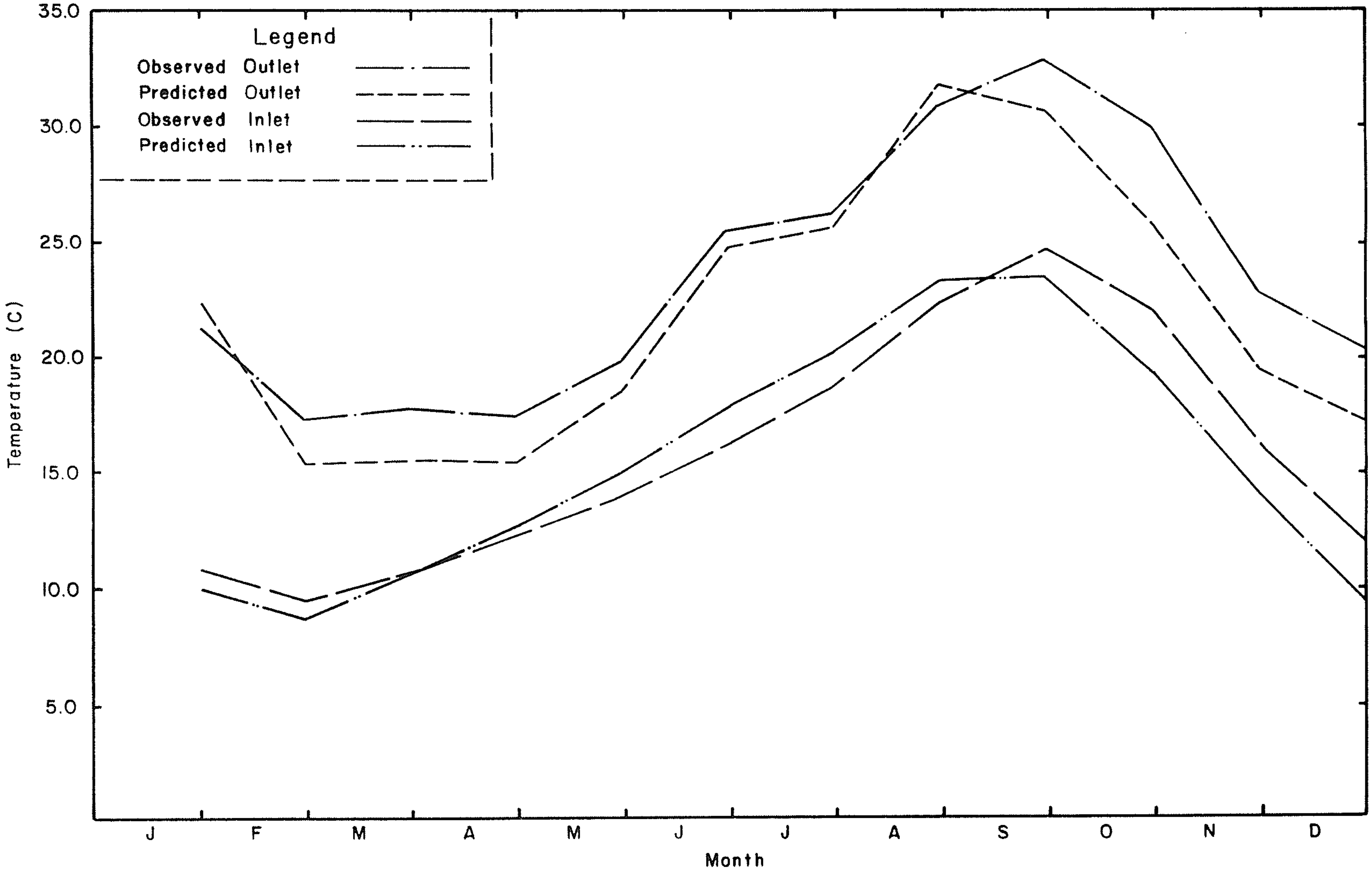
Figure: 2-54



Observed and Predicted Temperatures at Location 502.0 for 1976
Figure: **2-55**



Observed And Predicted Inlet And
Outlet Temperatures For 1975
Figure: 2-56



Observed And Predicted Inlet And
Outlet Temperatures For 1976
Figure:2-57

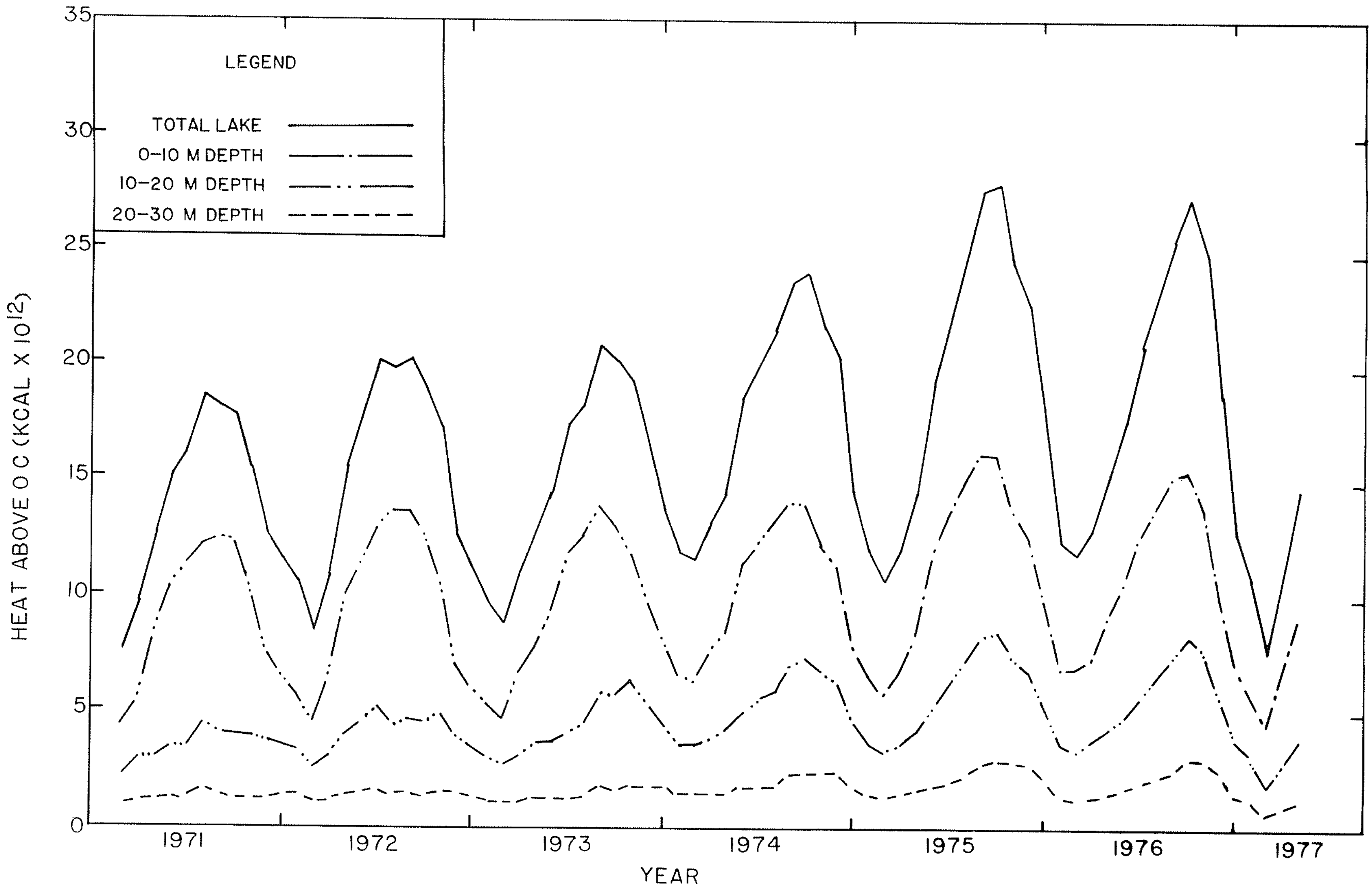


Figure: **2 - 58** **Heat Content of Lake Keowee**

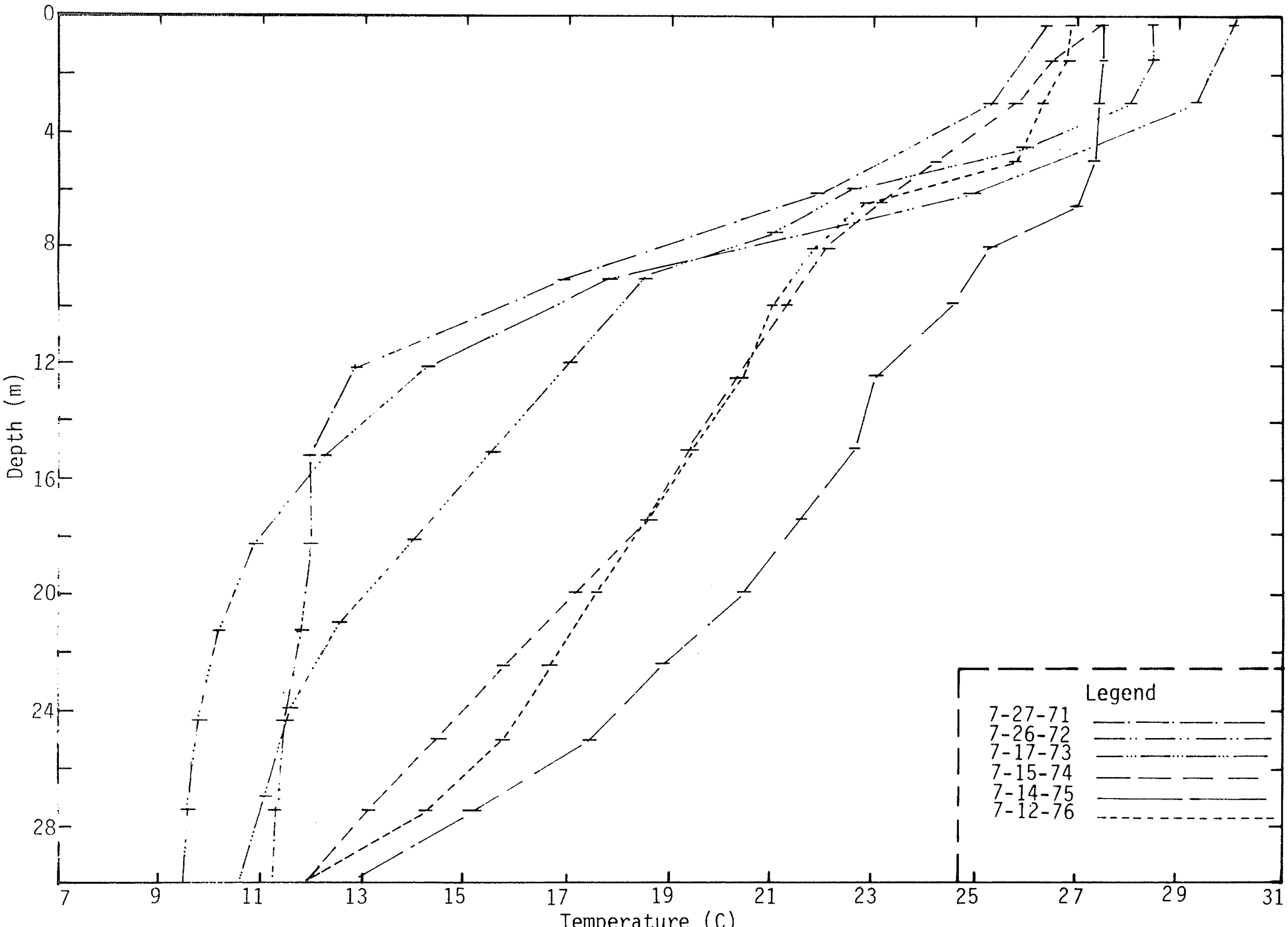


Figure: **2-59** Vertical Temperature Profiles for Location 501.0 During Stratified Periods.

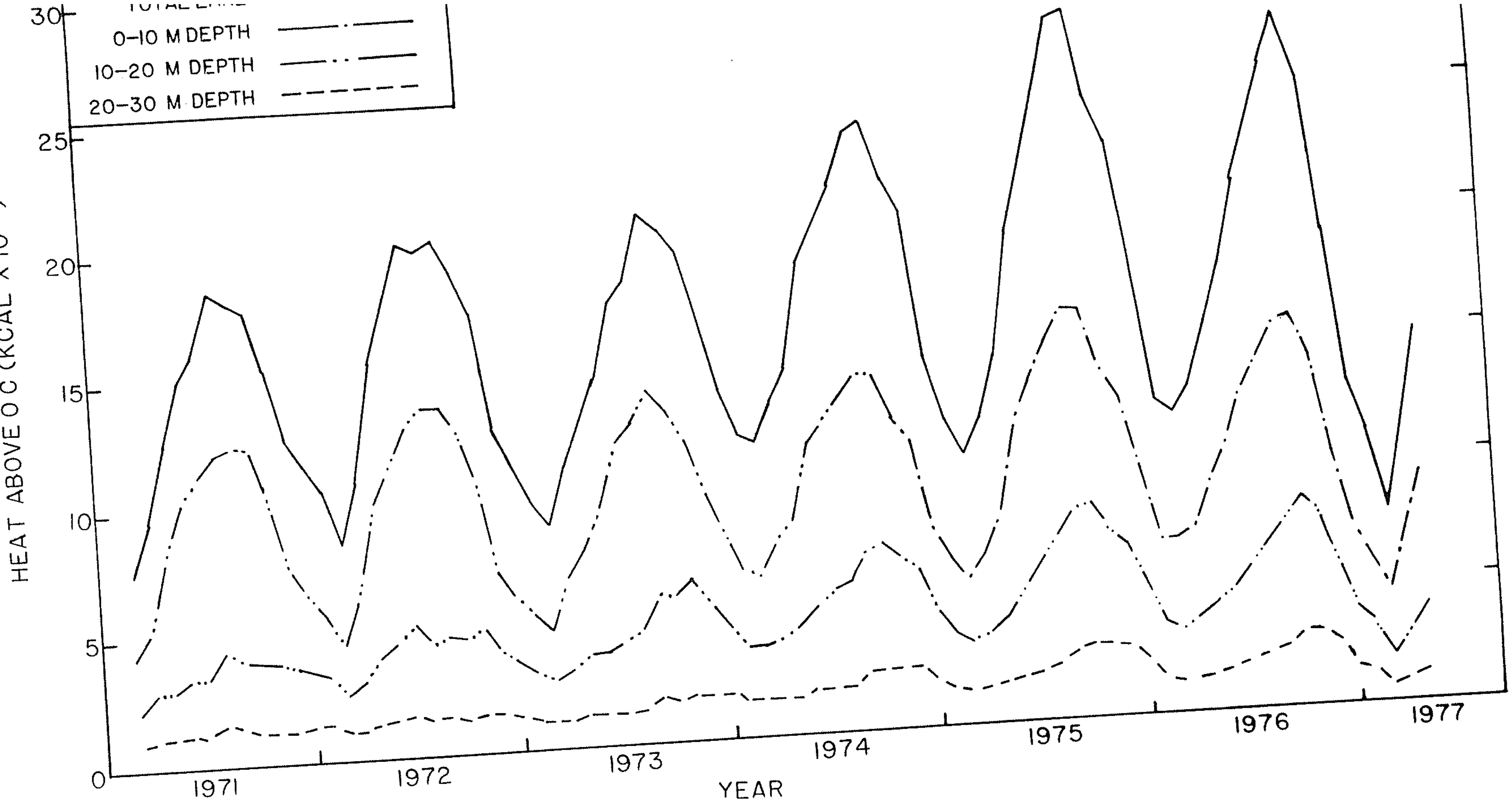


Figure: 2-58

Heat Content of Lake Keowee

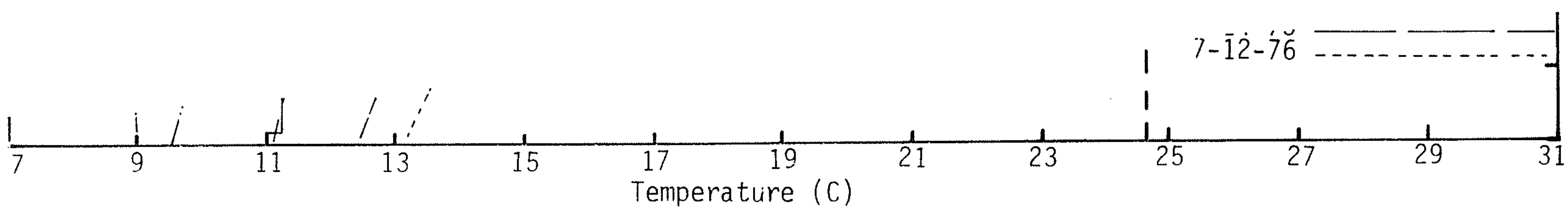


Figure: 2-60

Vertical Temperature Profiles for Location 504.0 During Stratified Periods.

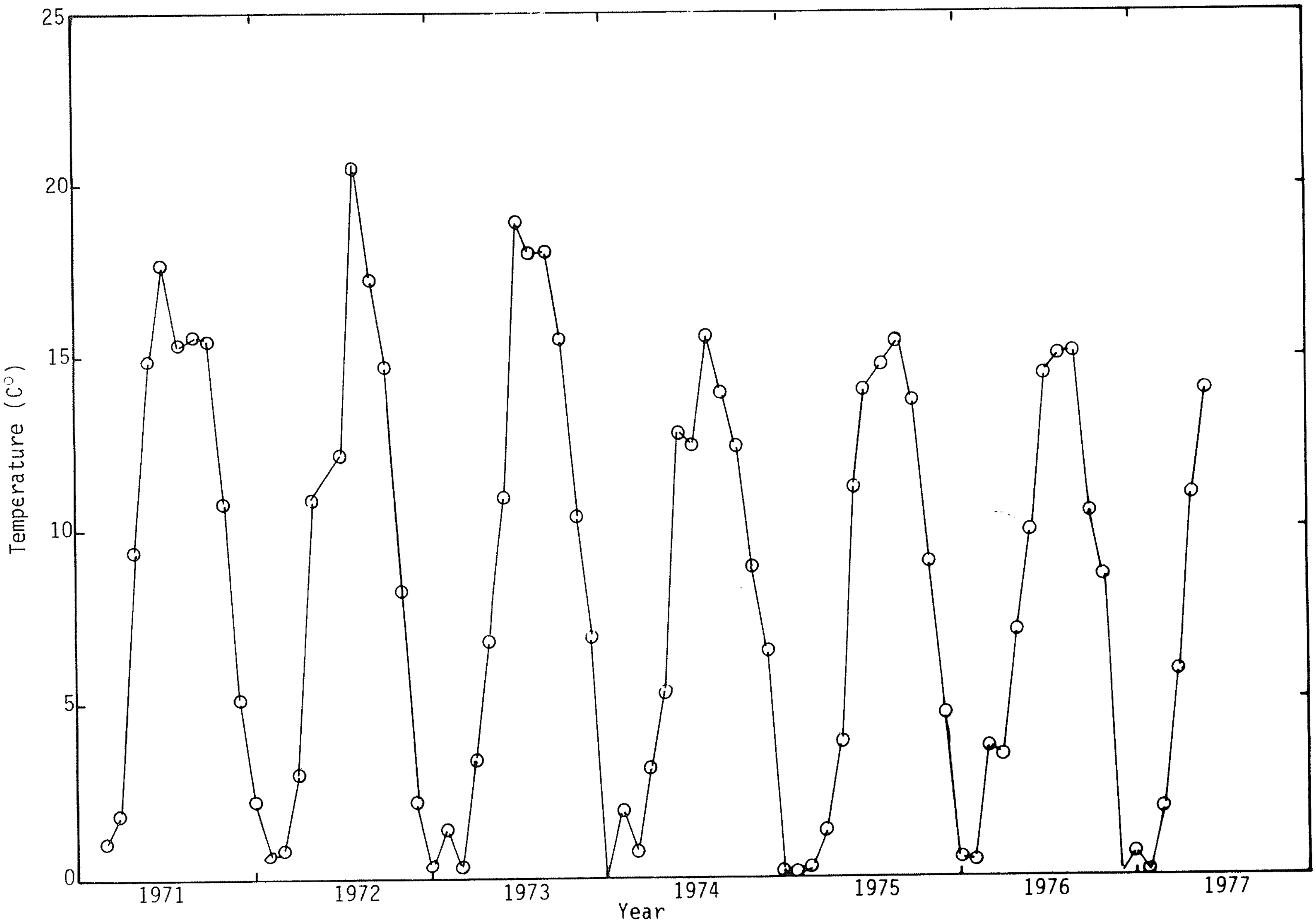


Figure: **2-61** Temperature Difference Between Surface and Bottom (≤ 30m) for Location 501.0

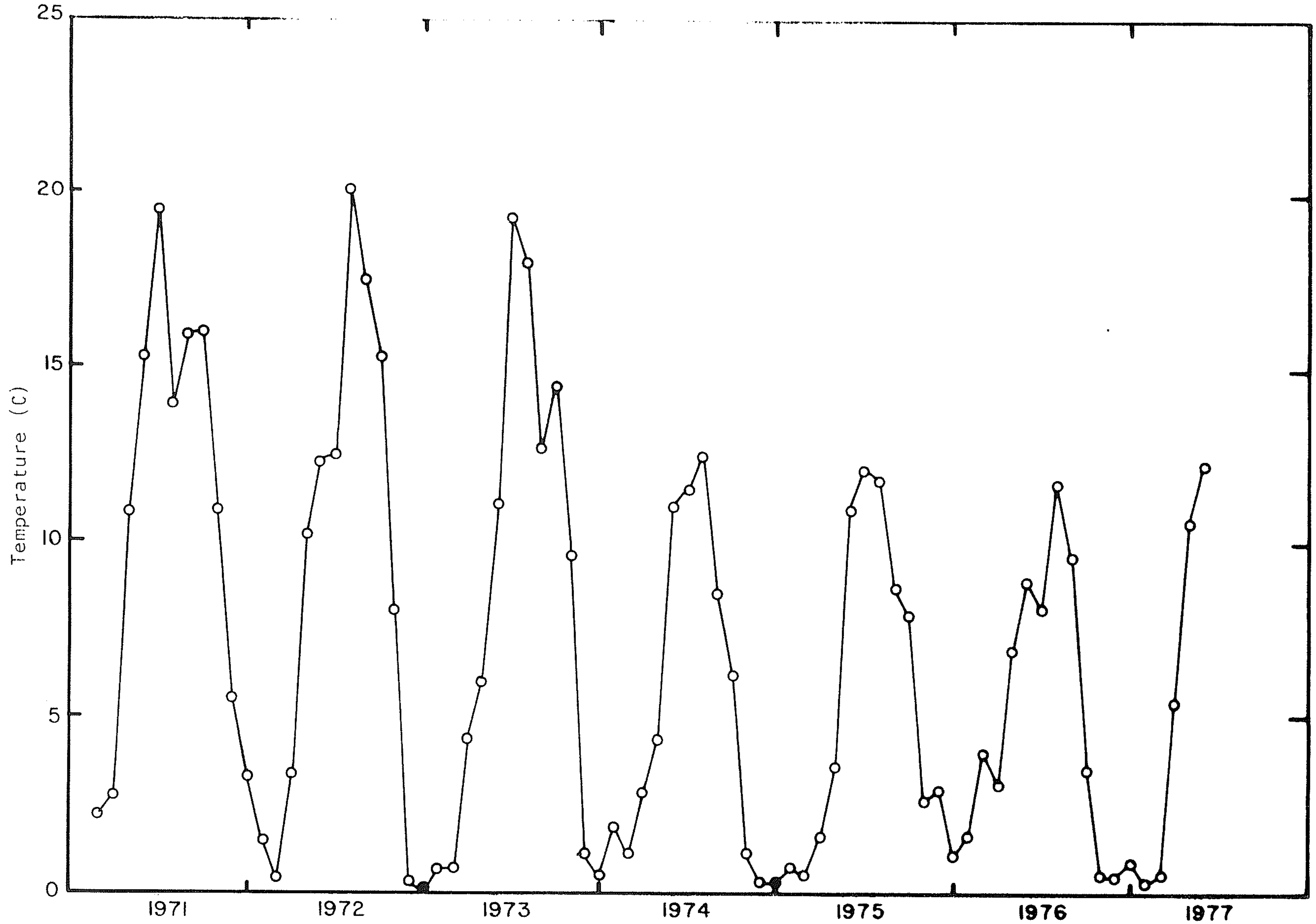


FIGURE: **2-62**

Temperature Difference Between Surface and Bottom (≤ 30m) from Location 502.0

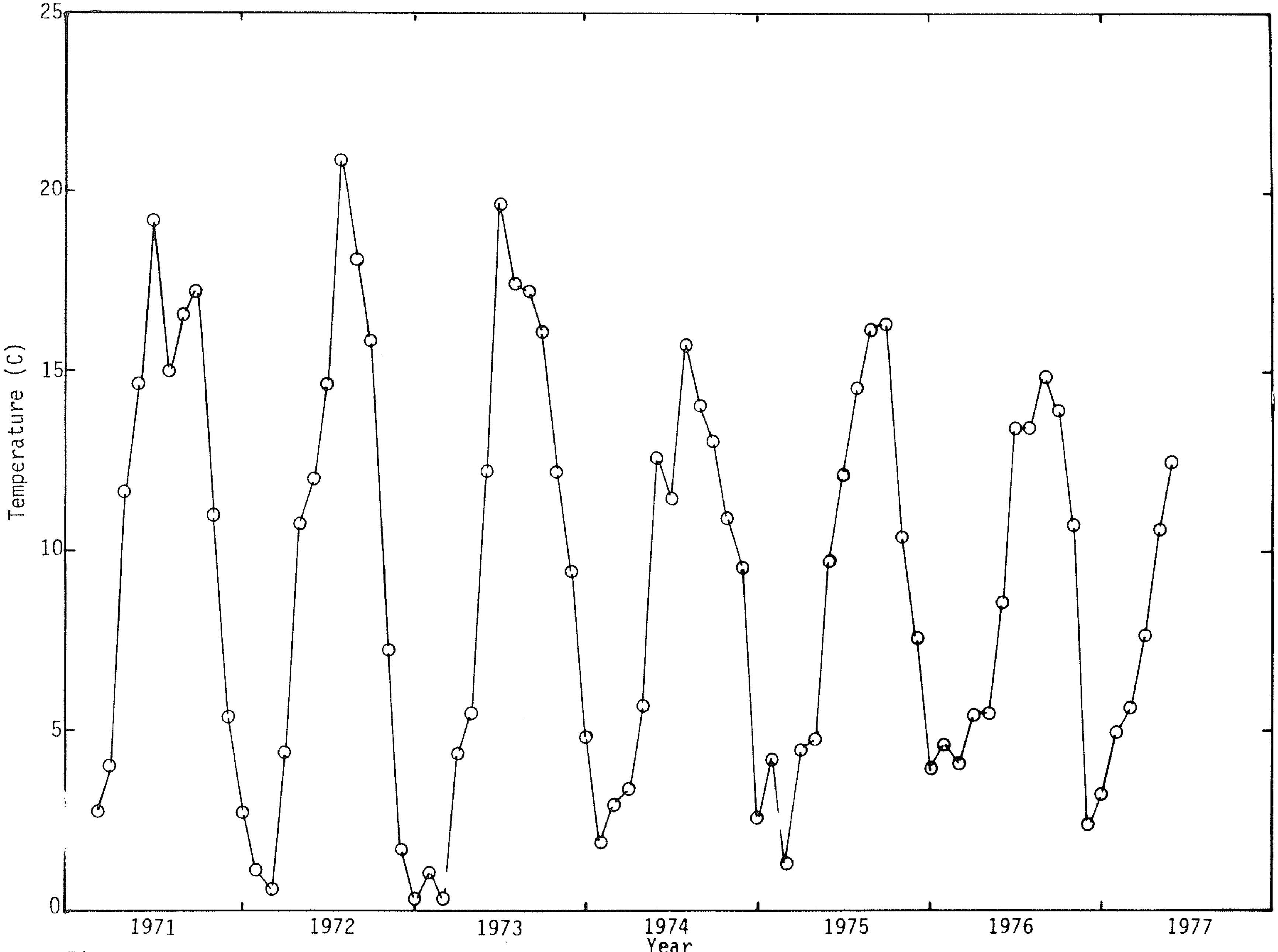


Figure: **2-63**
Temperature Difference Between Surface and Bottom ($\leq$ 30m) from Location 504.0

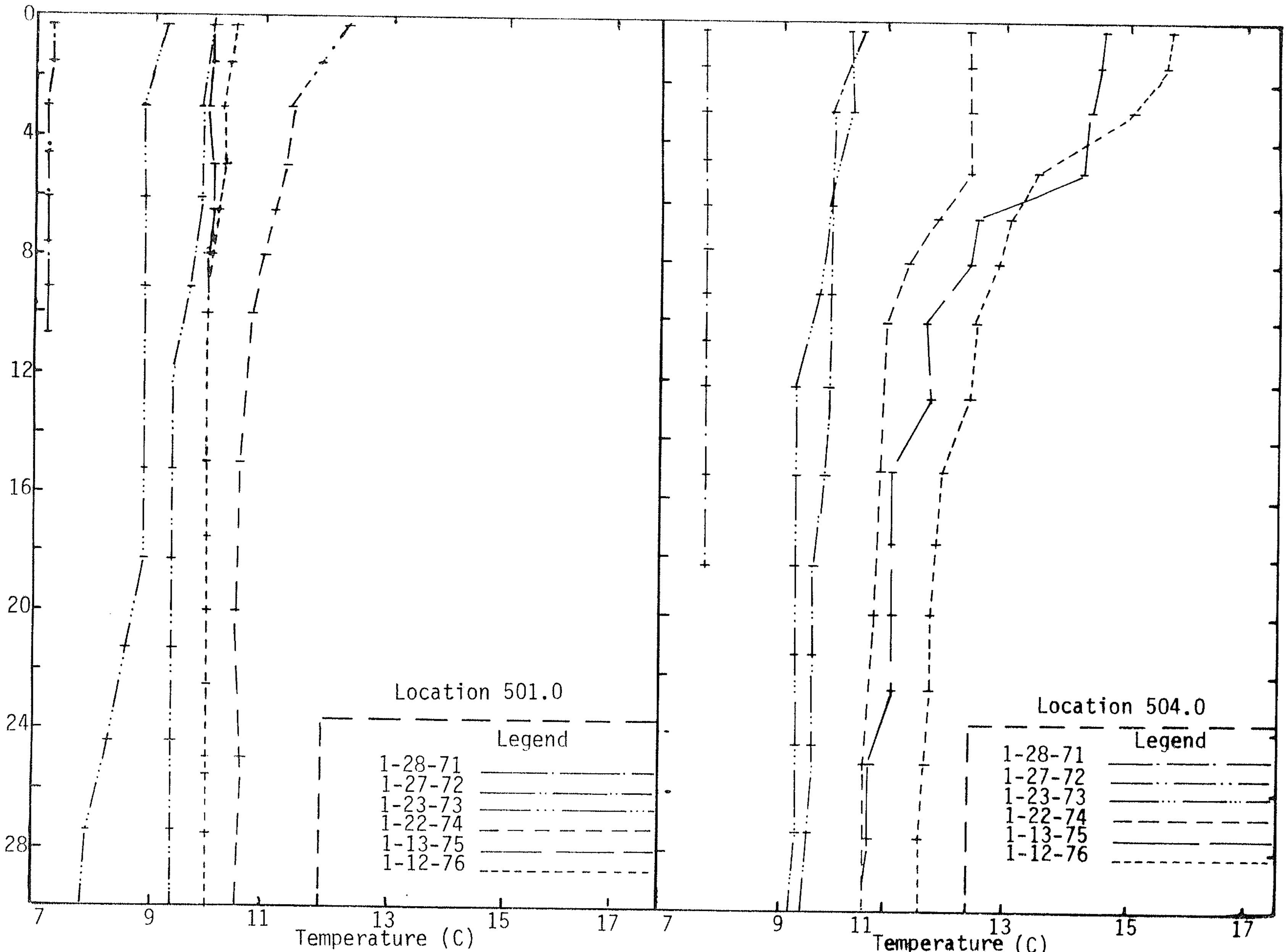


Figure: 2-64 Vertical Temperature Profiles for Locations 501.0 and 504.0 During Destratified Periods.

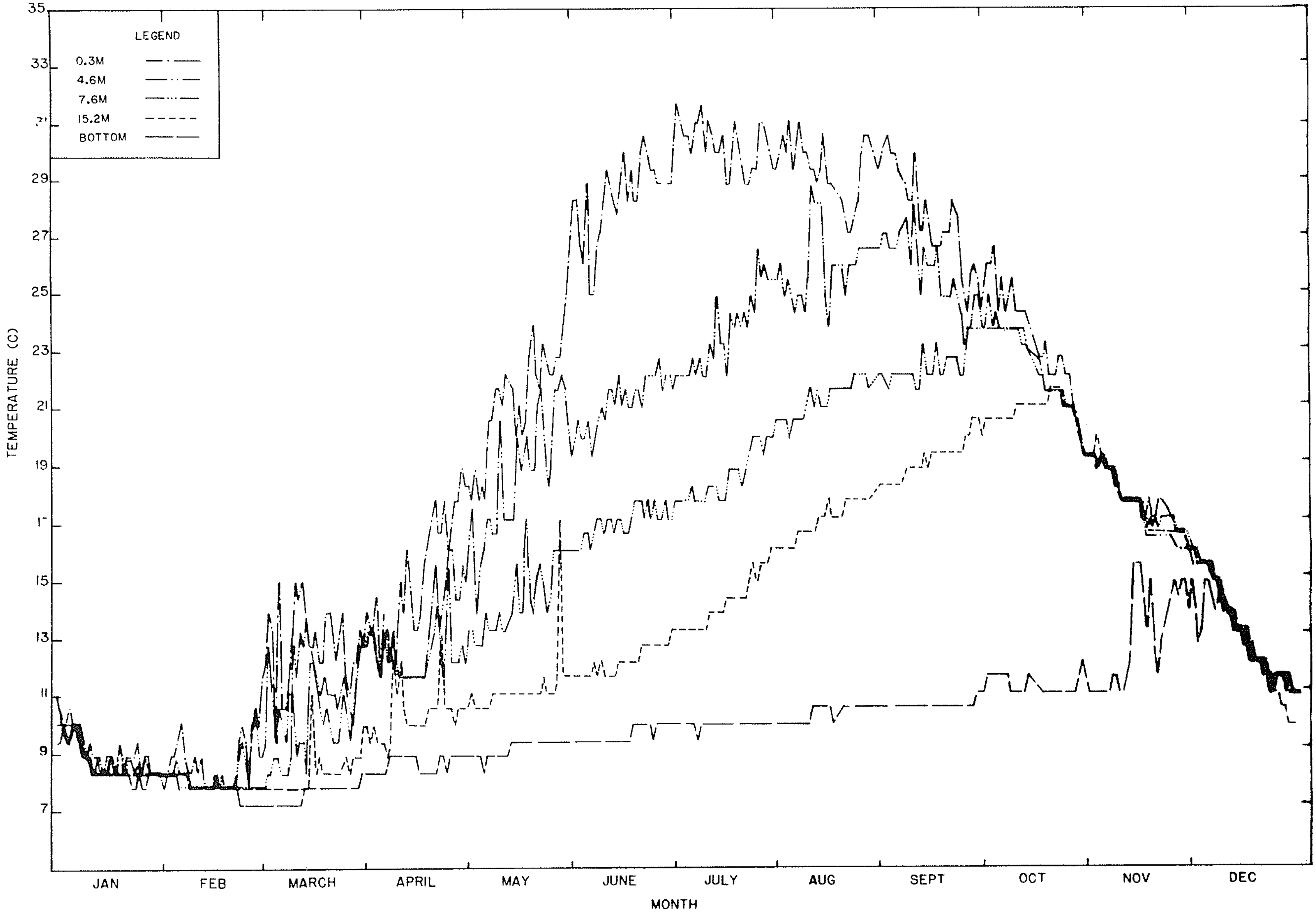


Figure: 2-65

Water Temperatures from Location
502.0 During 1973

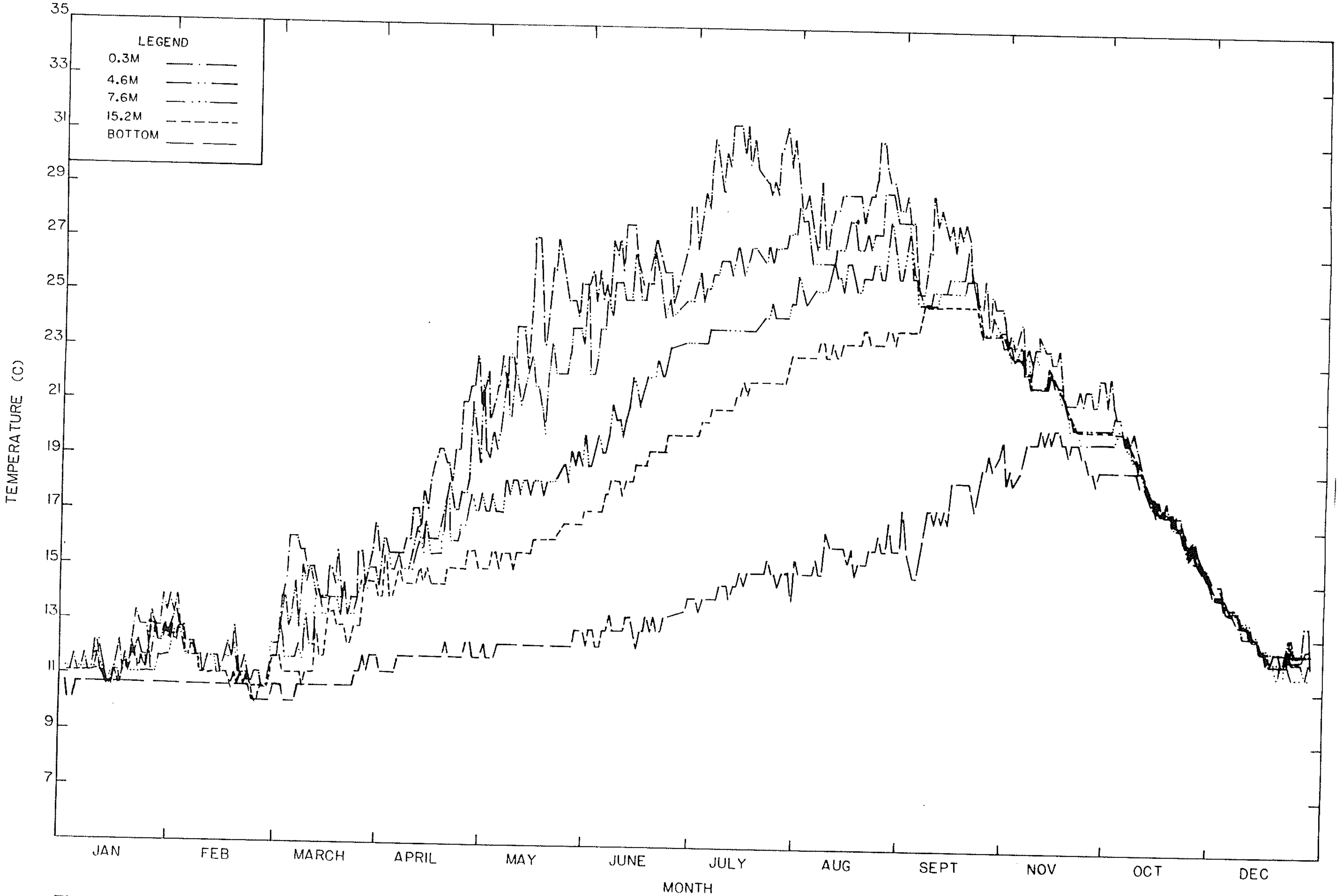


Figure: 2-66

Water Temperatures from Location
502.0 During 1974

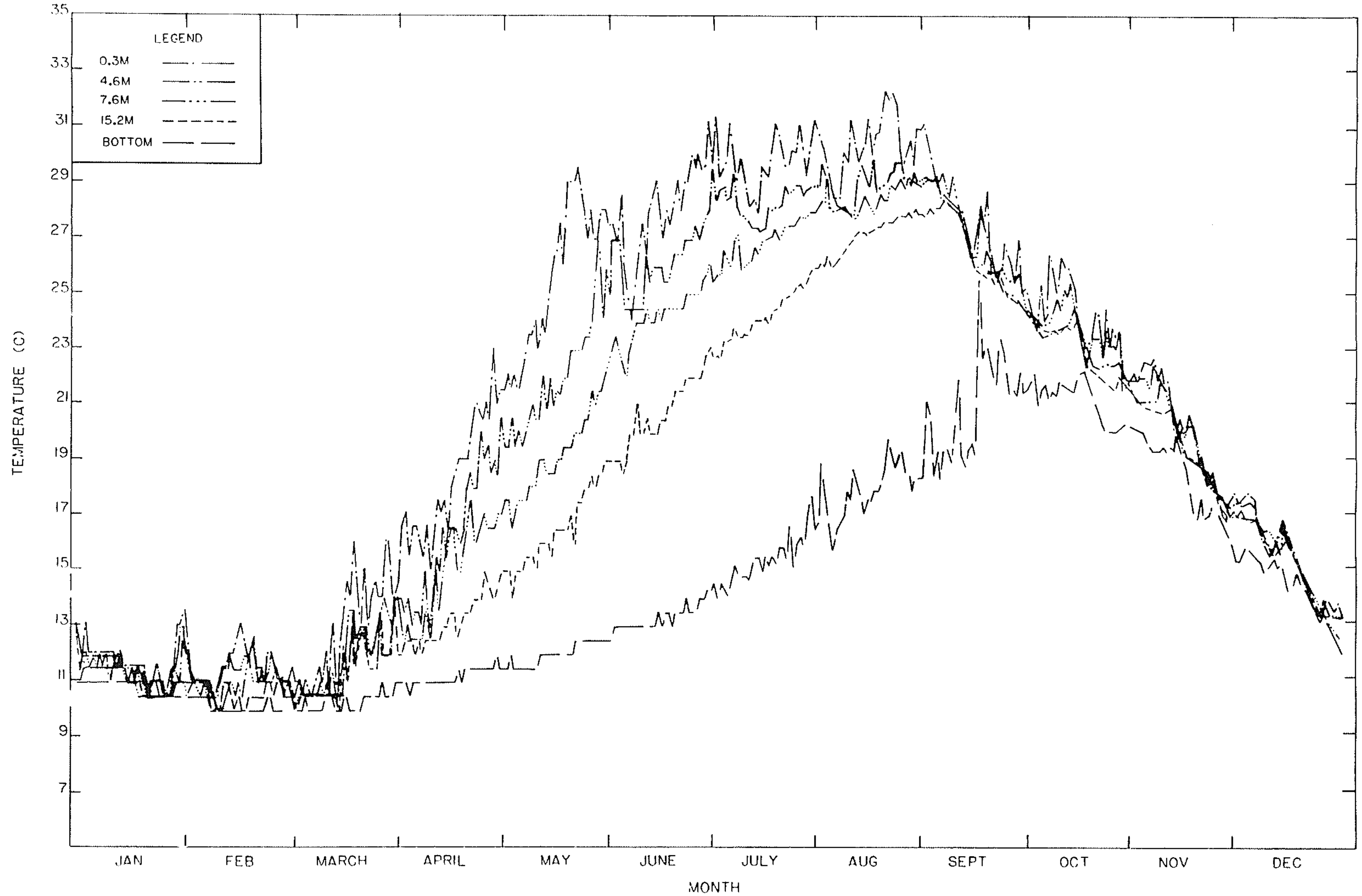


Figure: 2-67

Water Temperatures from Location
502.0 During 1975

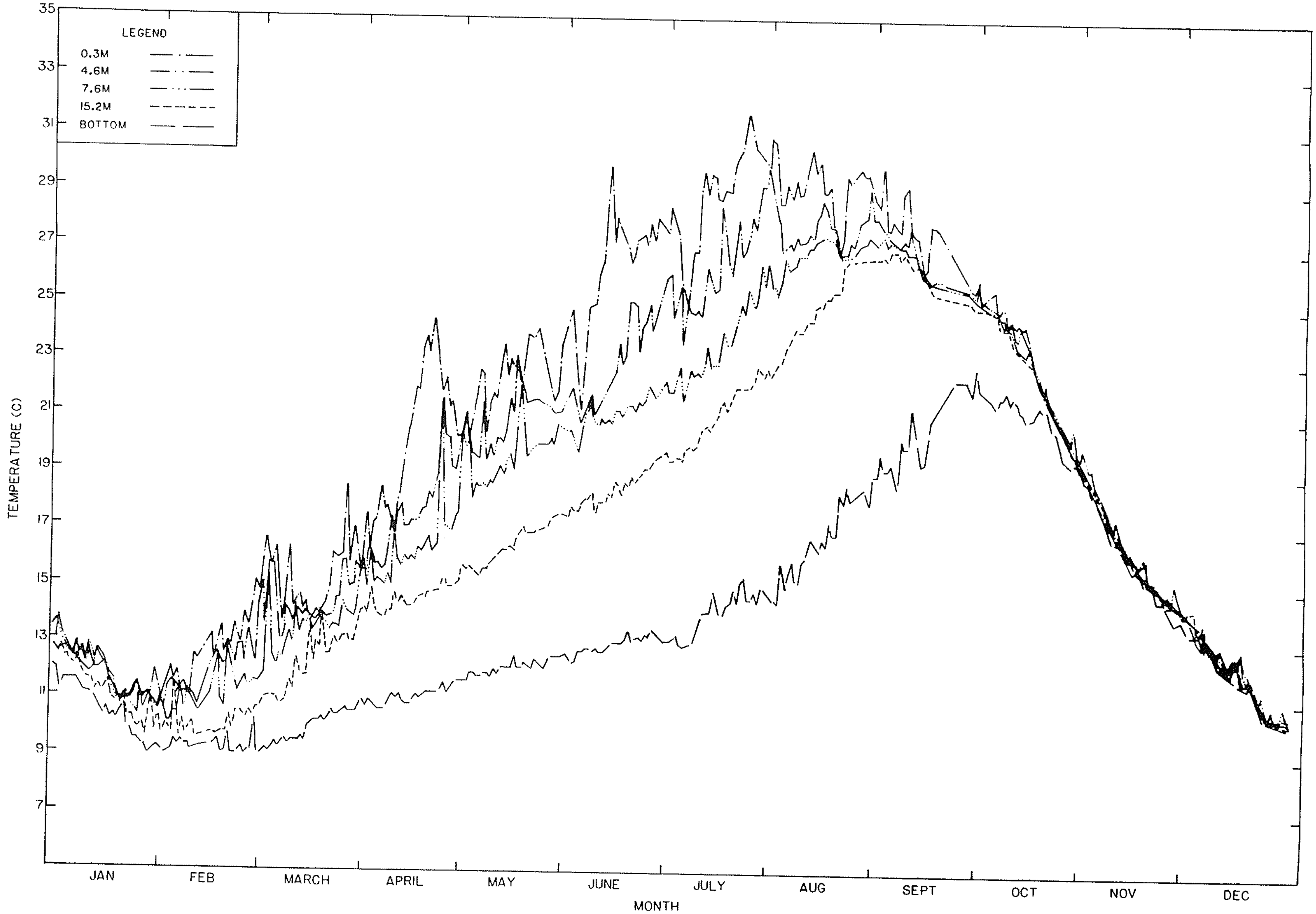


Figure: 2-68

Water Temperatures from Location
502.0 During 1976

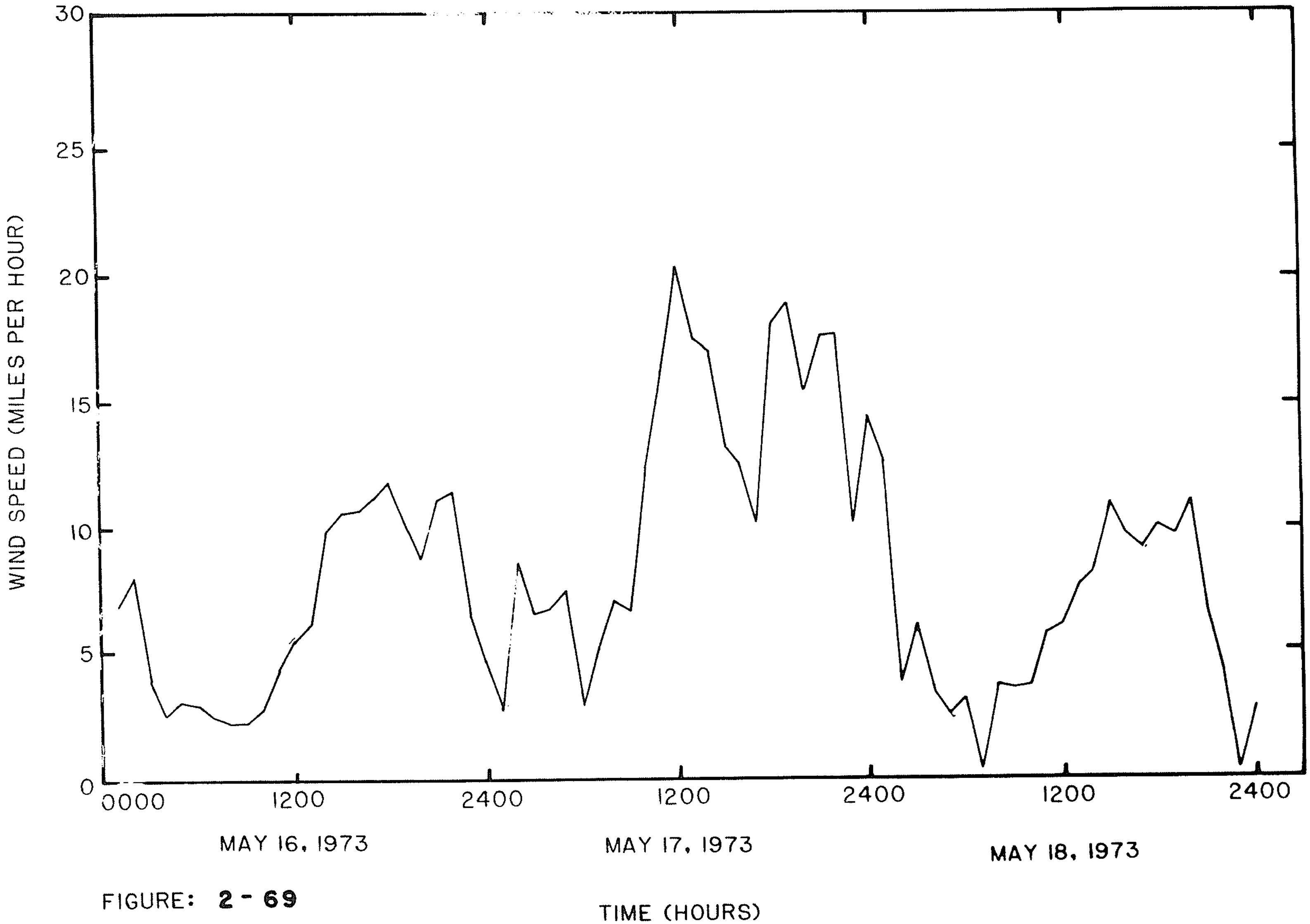


FIGURE: **2 - 69**

Hourly Average Wind Speeds from Oconee Nuclear Station

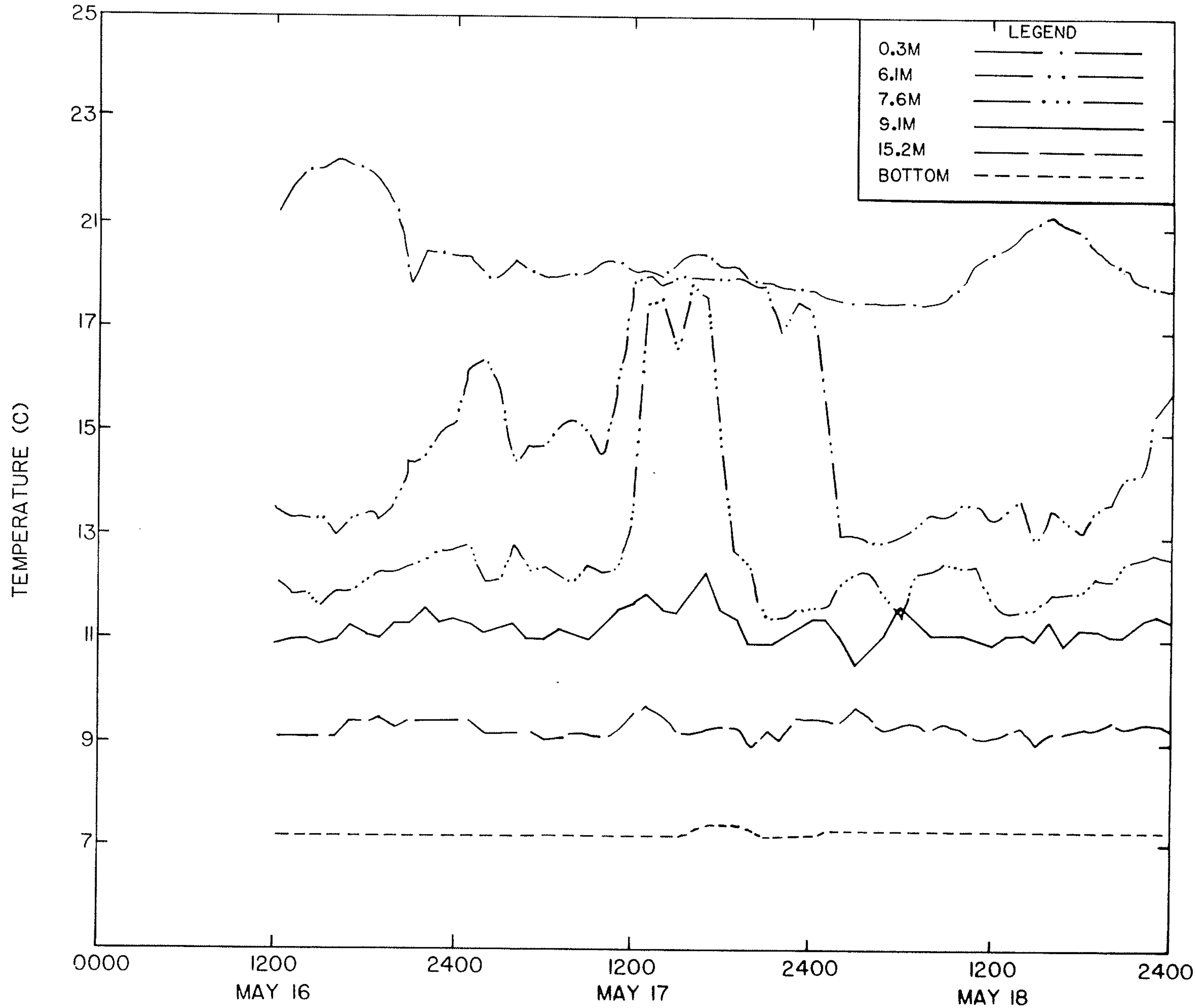


Figure: 2 - 70 Average Hourly Temperatures at Location 502.0 for May 16, 17, and 18, 1973

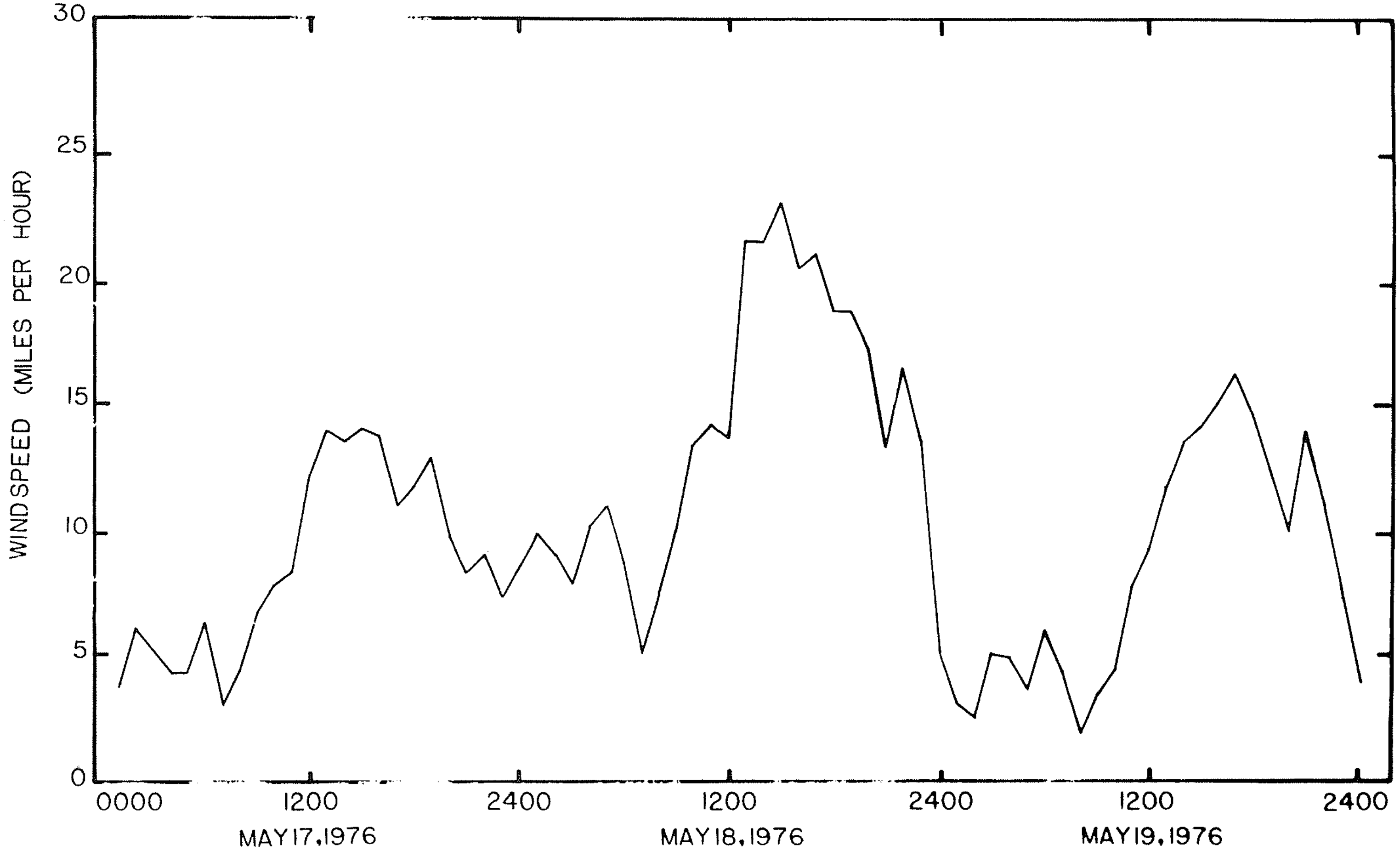


FIGURE 2-71

Hourly Average Wind Speeds at Oconee Nuclear Station

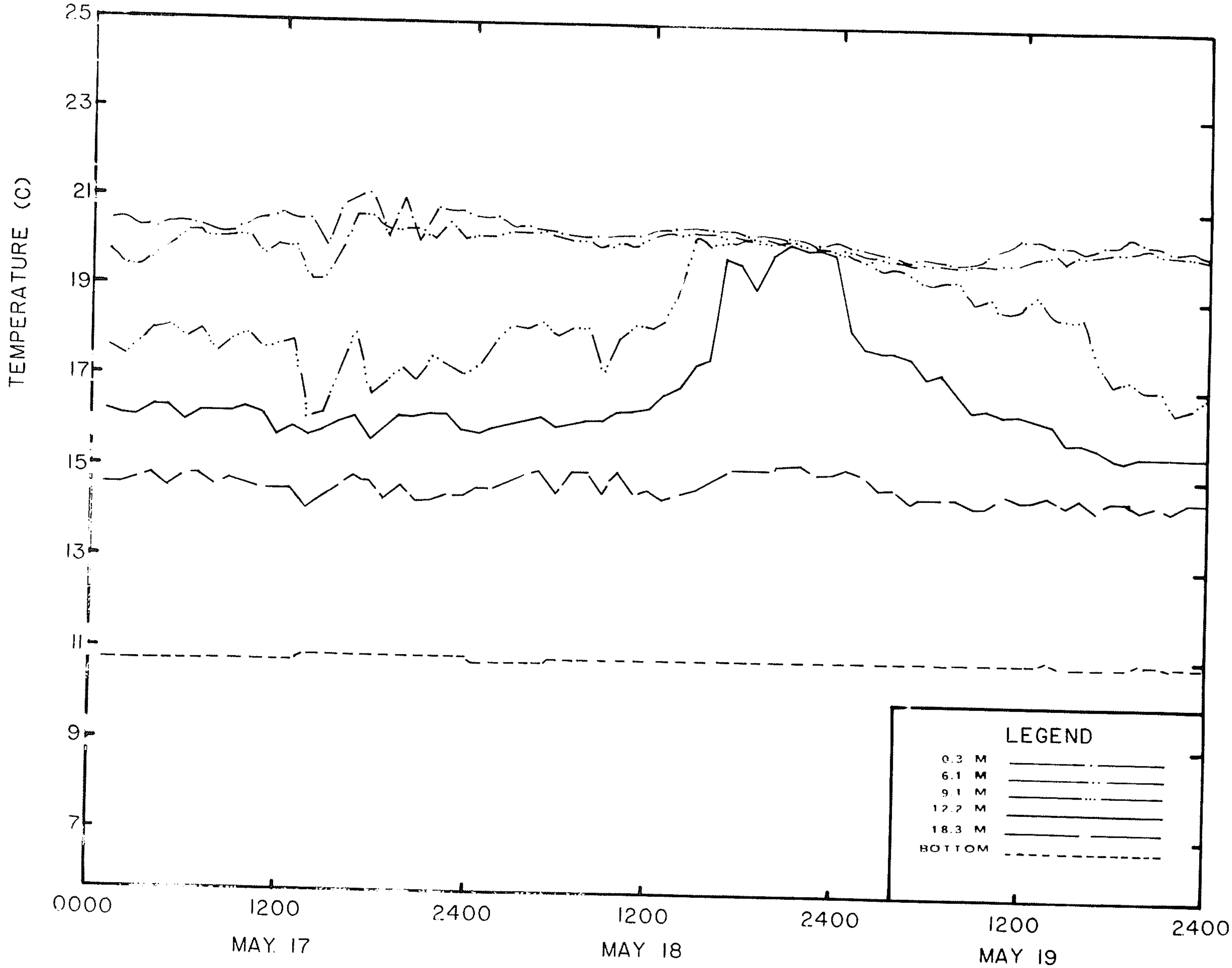


FIGURE: **2-72** Average Hourly Temperatures at Location 504.0 for May 17, 18, and 19, 1976

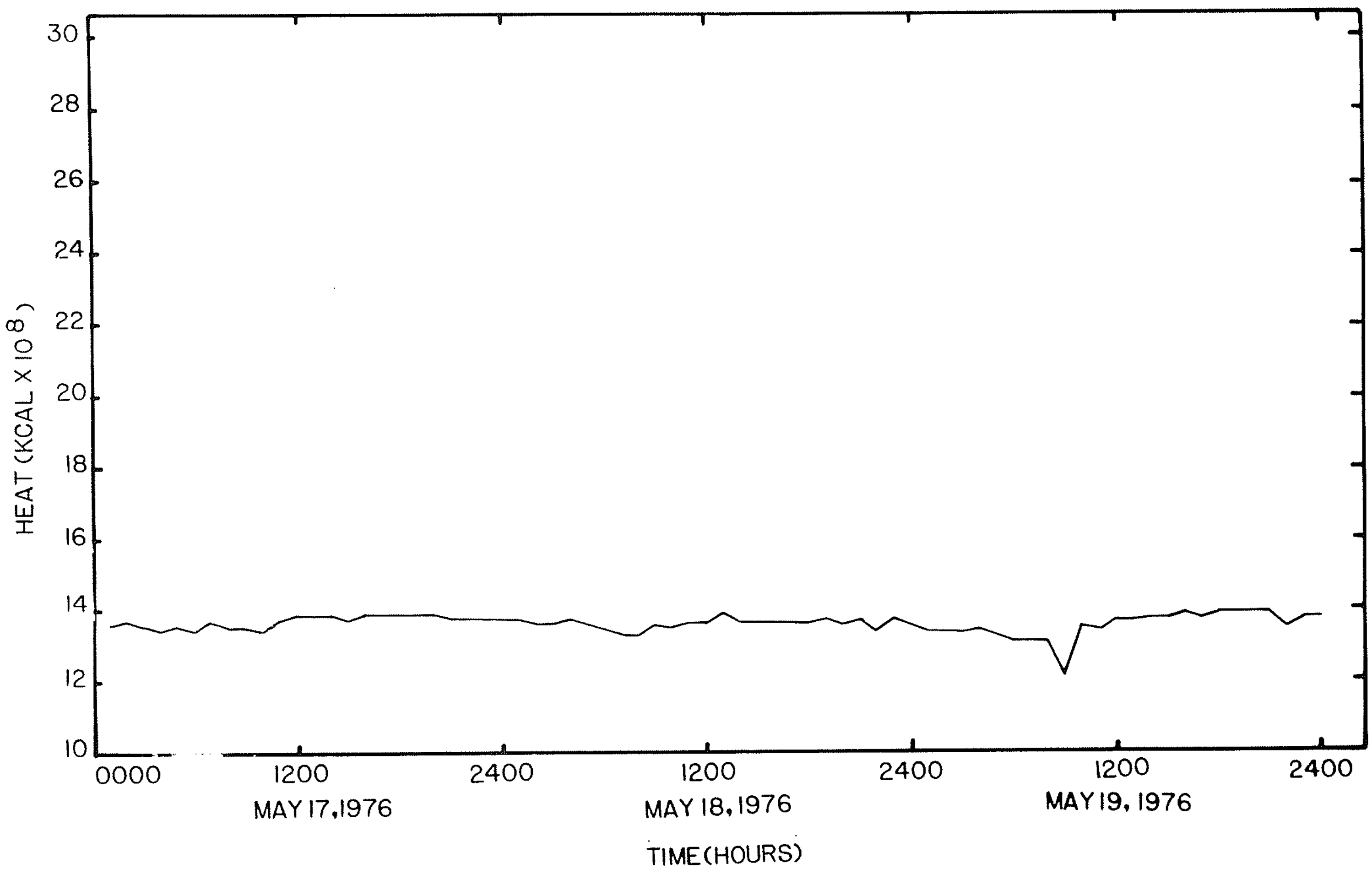


FIGURE: **2-73**

Hourly Average Heat Rejected by Oconee Nuclear Station

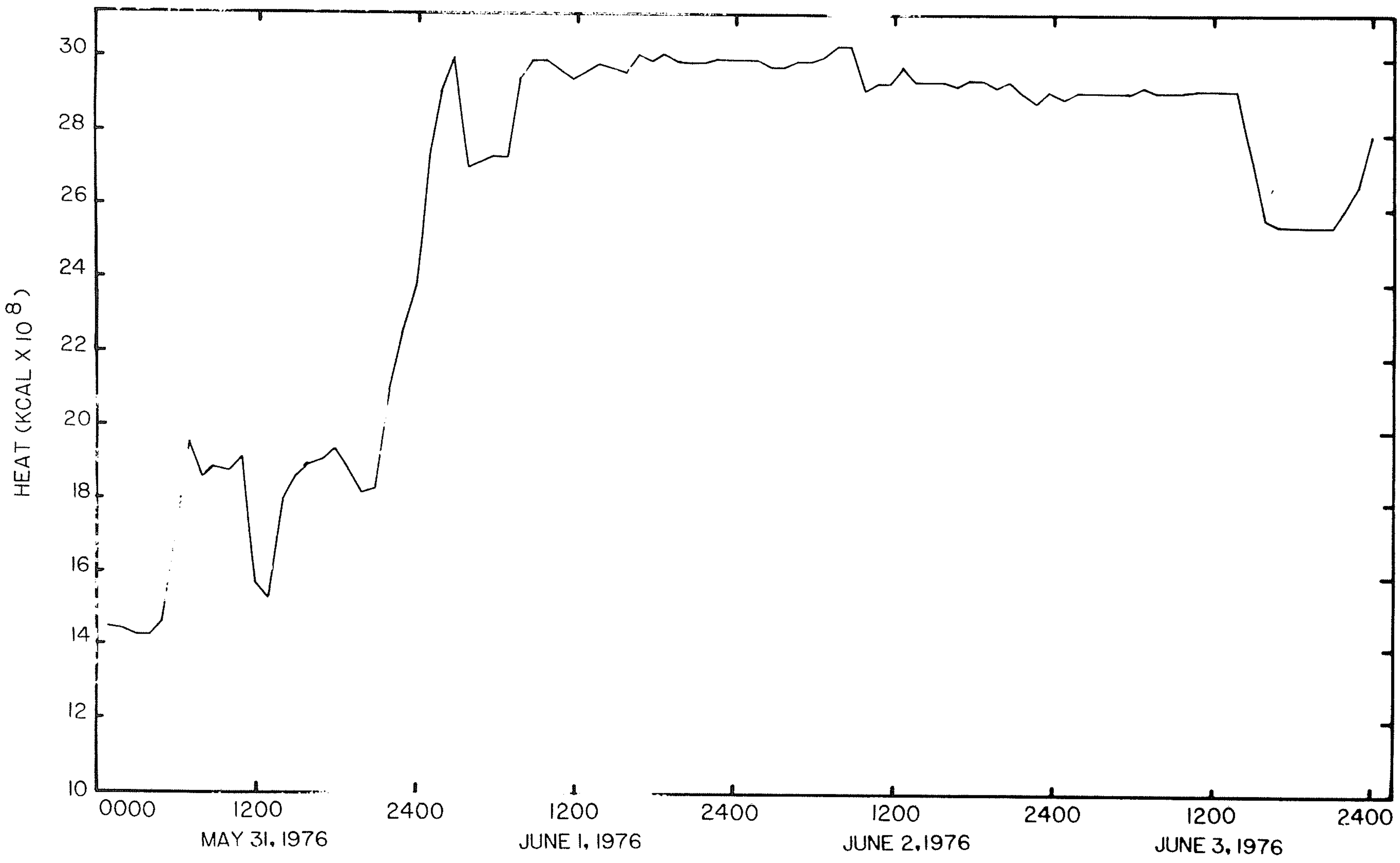
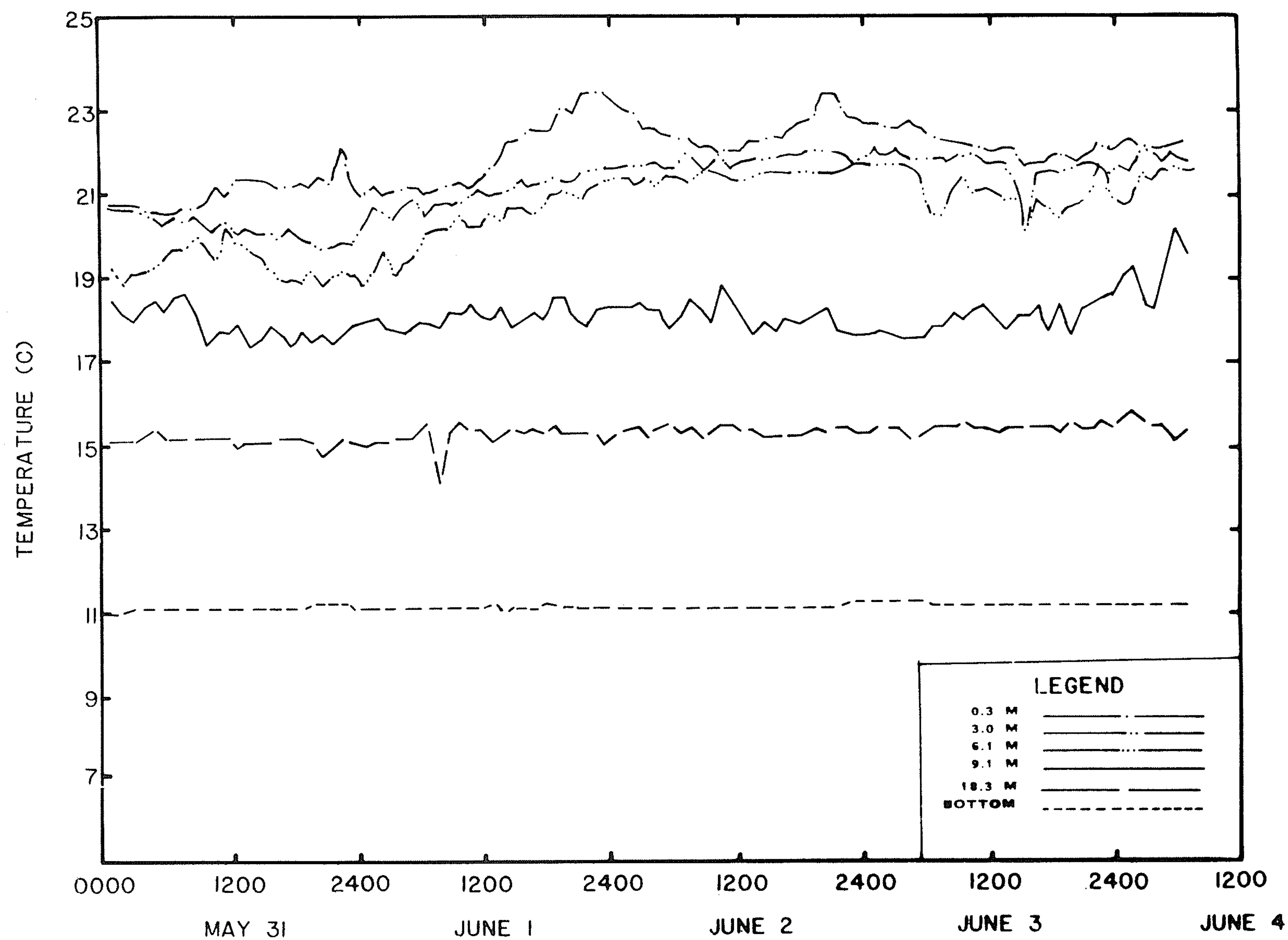


FIGURE: **2 - 74**

Hourly Average Heat Rejected by Oconee Nuclear Station



Average Hourly Temperatures at Location 504.0 for May 31, June 1, 2, 3, and 4, 1976

FIGURE: **2-75**

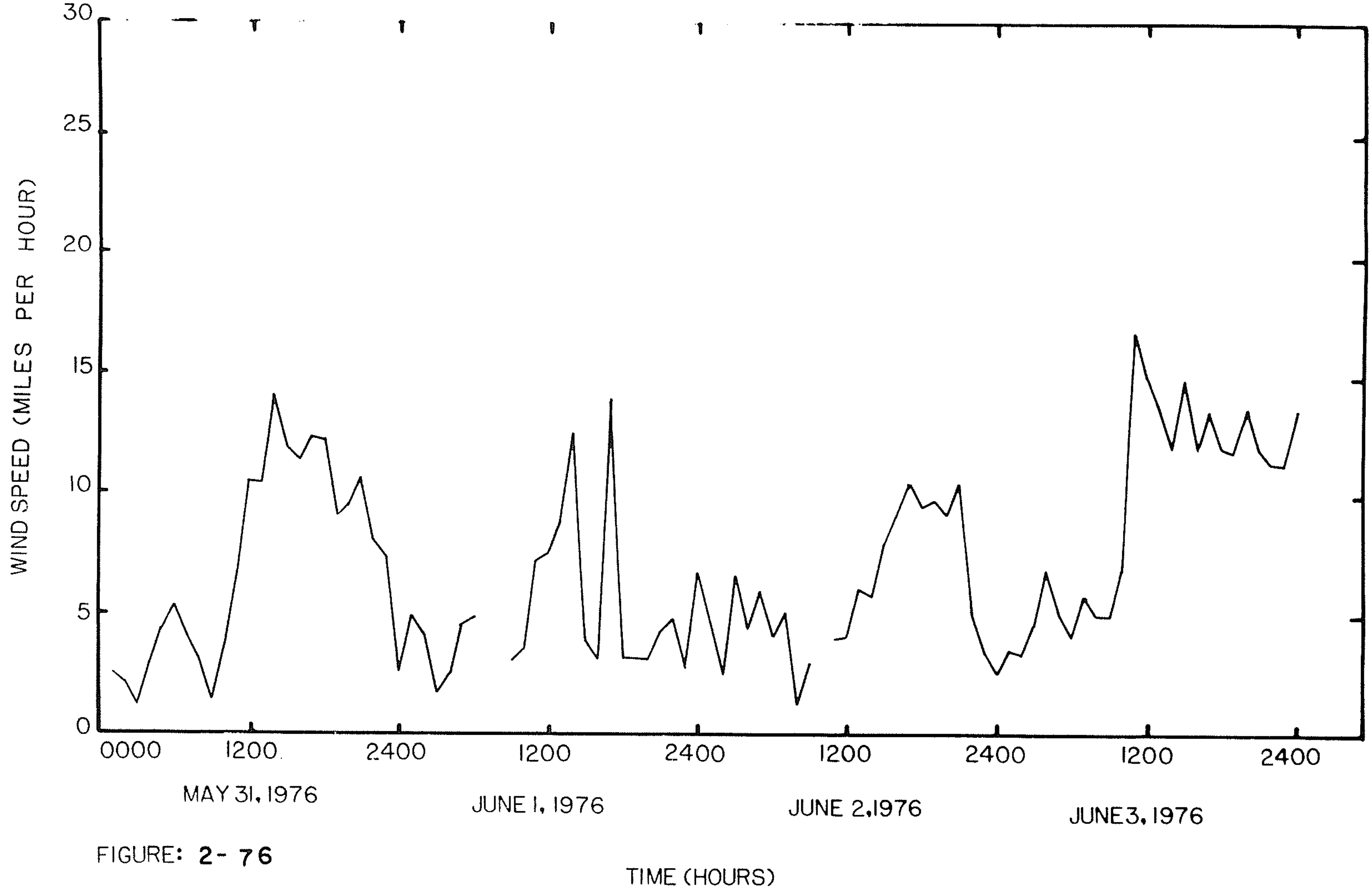


FIGURE: **2- 76**

Hourly Average Wind Speeds at Oconee Nuclear Station

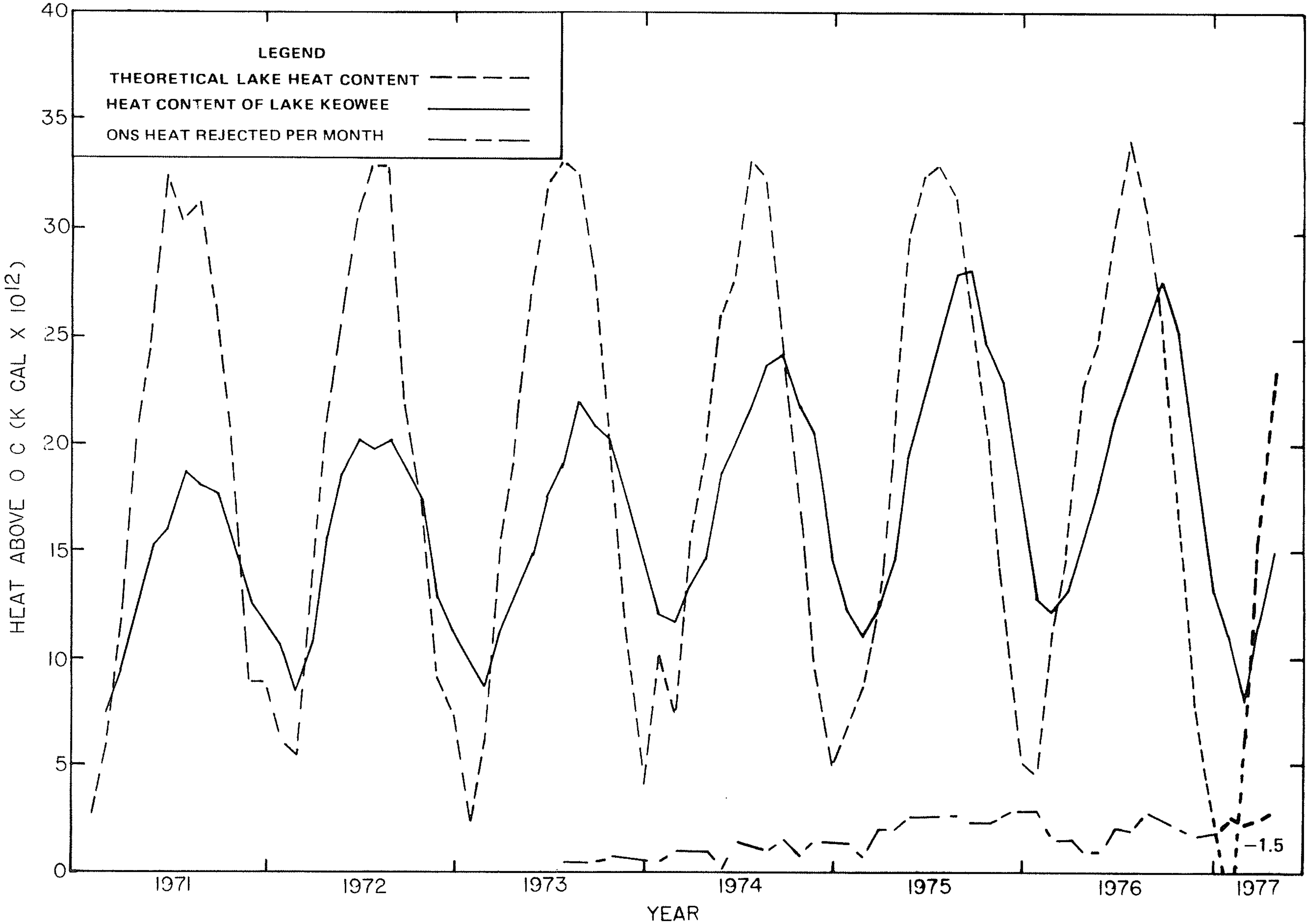


Figure: 2-77 Heat Content Considerations for Lake Keowee

CHAPTER 3 WATER CHEMISTRY

INTRODUCTION

Lake Keowee was created (May 1968 through April 1971) by impounding the Little River and Keowee River. The impoundment of the two rivers created two basins separated by an isthmus of land. This isthmus was removed creating a connecting canal joining the two arms of the lake. Due to the limiting action of the connecting canal, each arm maintains slightly different chemical characteristics However, the operation of Oconee Nuclear Station (ONS) and the emplacement of the skimmer wall (Figure 1-4) across the entrance of the ONS intake canal, enhances mixing between the two arms of the lake. Water is drawn into the intake canal at a depth of 20 through 27 meters (opening in the skimmer wall) from the Little River arm by the operation of the Condenser Cooling Water (CCW) pumps and subsequently discharged to the surface waters of the Keowee River arm. In the summer and early fall months, the bottom waters drawn into the CCW system are characteristically colder, lower in dissolved oxygen, and higher in minerals and nutrients than the surface waters. Lake Keowee also serves as the lower reservoir for Jocassee Pumped Storage Station. Lake Jocassee, the upper reservoir, completed filling in December 1973. At this time pump storage operations began. The effects of these operations on Lake Keowee have been studied by Duke Power Company in conjunction with the study of thermal effects of ONS operation. Some of the data of these studies will be addressed in this report as part of the interaction of ONS with the Keowee-Toxaway Project.

Physical and chemical monitoring of Lake Keowee was initiated in 1971 to determine the influence of ONS operations on the water chemistry of the lake. The data obtained have been reported in previous reports (Duke Power Company 1973a, b; 1974a, b; 1975a, b; 1976) to the U. S. Atomic Energy Commission (USAEC) and Nuclear Regulatory Commission (NRC). These data form the basis for the conclusions presented in this report. The objectives of this study were to provide baseline data, assess the effects of ONS operation on Lake Keowee water chemistry, and to provide supporting data for the benthos, plankton, periphyton, and fish monitoring programs.

METHODS AND MATERIALS

FREQUENCY AND LOCATIONS FOR SAMPLING

Profile measurements of temperature, dissolved oxygen, pH, and specific conductance were performed at monthly intervals on Lake Keowee from January 1971 through December 1976. The number of sampling locations varied during this period; however, there were no less than eight locations being sampled at any given time. Initially only Locations 500.0, 501.0, 502.0, 503.0, 504.0, 505.0, 506.0, and 507.0 (Figure 3-1) were sampled to obtain pre-operational data for Lake Keowee. These eight locations were sampled from January 1971 through June 1973 at which time Locations 508.0 (Oconee Nuclear Station discharge cove) and 509.0 (Station side of the intake skimmer wall) were added to coincide with the operational phase of monitoring for ONS effects. Sampling locations and the frequency of sampling for these locations are presented in Table 3-1.

In conjunction with the Lake Keowee monitoring program, Lakes Hartwell and Jocassee were also sampled on a monthly basis. Profile monitoring began on Lake Hartwell in July 1965 at five locations (Figure 3-2) and on Lake Jocassee in August 1973 at twelve locations (Figure 3-3). In addition to the monthly sampling, a weekly dissolved oxygen (DO) monitoring program was initiated in 1973. The purpose of the weekly DO study was to assess DO concentrations in the immediate vicinity of ONS from May through November when intake water was low in DO. Samples were collected from the ONS discharge structure (6.0 m depth), Keowee Hydro intake (0.3 m depth), and Keowee Hydro discharge (1.5 m depth). In 1974, the ONS intake (0.3 m depth) and Location 605.0 (0.3 m depth) were added to the weekly monitoring program.

During plume surveys (Chapter 2), DO was measured in addition to temperature in order to map areas of the lake affected by the discharge of low DO water and compare areas affected by the discharge of low DO water with predicted areas (USAEC 1972). The locations and depths of these measurements were addressed in Chapter 2.

FIELD PROCEDURES

During the preoperational phase of the chemistry program (January 1971 through July 1973), temperature and dissolved oxygen were measured _in situ_ at 10 foot intervals from 1 foot below the surface to 1 foot above the bottom. Specific conductance and pH were analyzed in the laboratory by the methods specified in Table 3-2. Secchi disc readings for water transparency were recorded at each location. In August 1973, specific conductance and pH were added to the _in situ_ parameters. At this time, the profile sampling depths were converted to meters and _in situ_ measurements were made at depths of 0.3 m, 1.5 m, 3.0 m, 5.0 m, 6.5 m, 8.0 m, 10.0 m, and at 2.5 m intervals to 1 m above the bottom. The secchi disc method was replaced during this time by surface illumination and 1% incident light. In September 1976, oxidation-reduction potential was added to the _in situ_ parameters (Table 3-2). Manufacturer's recommended calibration procedures were performed before profile sampling. Methods for the measurements of each of these parameters are presented in Table 3-2.

Weekly DO samples were analyzed by azide modification of the Winkler DO titration (APHA et al. 1971). Measurements for DO concentrations during the plume surveys were obtained by the method specified in Table 3-2.

A diaphragm pump was used for collection of the samples to be analyzed in the laboratory. Samples were taken at 5 m intervals from 0.3 m to 1 m from the bottom. Prior to the use of this collection method, samples were collected at 10 foot intervals by either a Van Dorn water sampler or a flexible impeller pump; however, some parameters, including nutrients, were not analyzed at all of these depths. Tests comparing these three types of sampling devices insured that the method change did not appreciably affect any parameter analyzed. Biochemical oxygen demand (BOD) samples were collected at 0.3 m, 3.0 m and bottom depths. Mercury samples were collected, beginning in 1974, at the surface of locations 501.0, 508.0, 509.0, and 549.0 during February, May, August, and November. These months were selected to coincide with times when other heavy metal analyses were performed.

Samples were collected in linear polyethylene containers which were properly cleaned, rinsed and prior to sampling, appropriate preservative added.

Immediately after collection, the water samples were packed in ice and transported to the laboratory for analysis.

LABORATORY PROCEDURES

The analytical methods, references, preservatives, and detection limits for each parameter are listed in Table 3-2. All analytical methods are accepted by either the Federal government (USEPA 1974) and/or the scientific community. The detection limits employed were at the "state-of-the-art" level accepted by the scientific community for the type of analyses being performed.

During the six year period, new techniques for various analyses were employed to improve the analytical detection limits and laboratory efficiency. The major changes occurred in August 1973, when the Technicon Autoanalyzer II was introduced for analysis of nitrate-nitrite, soluble orthophosphate, total phosphorus, and soluble silica. At this time, iron and manganese analyses were switched from colorimetric to atomic absorption spectroscopy (Table 3-3). Ammonia and chloride analyses were performed by specific ion electrode beginning in August 1973 until automated methods (Table 3-3) were initiated in June 1974 for ammonia and June 1975 for chloride. In March 1976, due to high levels of phenol vapors in the laboratory, the analysis of ammonia nitrogen was discontinued pending an evaluation and correction of the problem. In July 1976, the method was changed from the Berthelot Method to the Salicylate/Nitroprusside Method. Other method changes in laboratory analyses are noted in Table 3-3.

The precision and accuracy of the data were affirmed in accordance with the procedures recommended by the U. S. Environmental Protection Agency (1972).

DATA ANALYSIS

Data were divided into pre-operational (January 1971 through June 1973) and operational (July 1973 through December 1976) periods. Spatial variations within each of these periods were compared by grouping sampling locations into three areas; Little River arm (500.0, 501.0, 502.0), near-field (508.0, 504.0, 505.0) and far-field (506.0, 507.0, 549.0). Seasonal depth variations within each period were evaluated by pooling locations (500.0, 501.0, 502.0, 504.0, 505.0, 506.0, 507.0, 508.0, 549.0) and dividing the depths into top-depths (surface to ten meters), mid-depths (ten meters to twenty meters) and bottom depths (twenty meters to bottom). Means were calculated for the area subgroups and depth subgroups and used to construct the graphs used in this report.

Monthly dissolved oxygen (DO) data was used to calculate a volume weighted dissolved oxygen content for Lake Keowee. All sampling depths at Locations 500.0, 501.0, 502.0, 503.0, 504.0, 505.0, 506.0, and 507.0 were used to calculate a mean dissolved oxygen concentration for each date sampled. The mean DO for each depth was multiplied by the volume for that stratum. The DO content for each stratum was summed to obtain a total DO content for Lake Keowee during each month.

Data obtained in 1973 for the weekly DO monitoring program were not used in the data evaluation for this report due to an inconsistency in sampling and data. However, these data have been reported for Environmental Technical Specification requirements in previous reports (Duke Power Company 1973a, b).

Data were subjected to Pearson correlation analysis and factor analysis. Data analyses were performed on the Statistical Analysis System (Barr et al. 1976).

RESULTS AND DISCUSSION

The reduction in thermal stratification (Chapter 2) following ONS operations was accompanied by a change in the factors influencing water chemistry illustrated by a factor analysis (Barr et al. 1976) of the water chemistry data. The factor analysis indicated that prior to ONS operation runoff was the primary factor influencing the chemistry of the top ten meters of the lake, accounting for 43% of the chemical variations in this region of the lake (Table 3-4). The thermal regime, however, was the fourth factor and only accounted for 12% of the chemical variations in this region. Following ONS operations, the thermal regime shifted to the primary factor accounting for 33% of the variations in the top 10 meters of the lake.

Insufficient nutrient data prohibited factor analysis on the mid-depth region of the water column during the preoperational study period. Following ONS operation, redox potentials were the primary controlling factor in this region and accounted for 44% of the variability. The thermal gradients became a secondary factor in the 10 to 20 meter region of the lake and accounted for only 22% of the chemical changes. This was probably a result of the increased mixing caused by ONS operations.

In the 20 meter to bottom depths, temperature was the second factor in the preoperational period accounting for 32% of the variations. During the operational period, temperature was not a controlling factor. The primary factor in the bottom following ONS operations was redox potential. Therefore, the factor analysis indicated that ONS operations had little effect on the chemistry of the bottom waters.

DISSOLVED OXYGEN

Dissolved oxygen concentrations in Lake Keowee are dependent upon water temperature, gas transfer from the atmosphere, gas transfer through the water, and photosynthetic activity. In ideal solutions, dissolved oxygen concentrations are controlled by temperature. In non-ideal solutions, an indication of the magnitude of thermal control of dissolved oxygen concentrations is given by the correlation coefficient (r) between temperature and dissolved oxygen.

Prior to ONS operation, a significant correlation existed at all depths of lake Keowee, surface to ten meters ($r = -0.60$; $p < 0.02$), ten meters to twenty meters ($r = -0.60$; $p < 0.02$), and twenty meters to bottom ($r = -0.58$; $p < 0.02$). After ONS began operation, significant correlations continued to exist throughout the water column with the surface to ten meter correlation remaining the same as the preoperational correlation. However, the mid-depth correlation ($r = -0.67$; $p < 0.02$) increased slightly and the bottom depth correlation ($r = -0.32$; $p < 0.02$) decreased.

The consistent correlation in the top ten meters of Lake Keowee obtained with both preoperational and operational data indicated that the thermal control of dissolved oxygen concentration was unchanged by ONS operations. The increased correlation obtained in the mid-depth region revealed that thermal influence on dissolved oxygen concentrations increased at these depths following ONS operation.

The decreased correlation in the twenty meter to bottom depths indicated that DO concentrations were probably influenced to a greater extent by biodegradation of organic material and to a lesser extent by temperature fluctuations.

At the time the Final Environmental Statement (FES) (USAEC 1972) and Environmental Technical Specifications (ETS) (Duke Power Company 1973a) were written, a value no less than 5.0 mg/l dissolved oxygen (Federal Water Pollution Control Authority 1968) was commonly used as the criterion for the support of a fishery. However, since that time, a value of 4.0 mg/l (USEPA 1976) has been accepted as a concentration necessary to support warm water fish species. Weekly dissolved oxygen data for the ONS intake and discharge revealed that the lowest dissolved oxygen concentrations occurred from August through September during each year (Figure 3-4). On eighteen occasions during the study, ONS intake dissolved oxygen values fell below 5.0 mg/l. The ONS discharge, however, only fell below 5.0 mg/l on fifteen occasions. On eight occasions, the ONS intake dissolved oxygen concentrations fell below 4.0 mg/l as opposed to only two occasions when values lower than 4.0 mg/l were observed at ONS discharge. The lowest value observed at both ONS intake and discharge was 3.4 mg/l and occurred in 1974.

The low dissolved oxygen concentrations observed at ONS discharge appeared to be a function of low intake dissolved oxygen concentrations. Furthermore, the higher dissolved oxygen values observed at the discharge compared to those observed at the intake indicated that considerable mixing and/or aeration occurred at CCW discharge. This rapid mixing with receiving waters has been observed at other power plants which possess discharge structures similar to the ONS discharge structure (Lee and Martin 1975).

The plume surveys also indicated that rapid mixing and dilution of the CCW discharge occurred since low dissolved oxygen concentrations recorded at the discharge structure were not observed on the surface of the lake (Figure 3-5 through 3-9). The lowest dissolved oxygen value observed at the discharge structure during plume surveys was 3.5 mg/l and occurred on September 10, 1975. At this time, concentrations of less than 5 mg/l covered only 0.3 km^2 (0.4%) of the total surface area of the lake. Typically, lowest dissolved oxygen values in the CCW discharge were recorded during the August and September surveys each year and affected only limited surface areas of Lake Keowee (Figure 3-5 through 3-9).

Predictions of areas affected by the discharge of waters low in DO concentrations were based on a physical comparison with Marshall Steam Station on Lake Norman in North Carolina (USAEC 1972). The observed areas in Figures 3-5 through 3-9 were measured and are tabulated in Table 3-6 along with predicted areas. Less surface areas were affected by the discharge of low DO concentrations than were predicted. The major factor responsible for the predicted areas being too large was higher dissolved oxygen concentrations at ONS intake than those observed at Marshall Steam Station. The rapid mixing and subsequent dilution of discharge water with receiving waters due to the submerged ONS discharge structure further reduced areas affected by low DO concentrations.

This dilution of the CCW discharge was further evidenced by weekly DO data taken at Keowee Hydro intake, discharge and Location 605.0. Regardless of the DO concentrations in the immediate influence of ONS, values at the Keowee Hydro discharge and Location 605.0 never fell below 5.0 mg/l during the operational study period (Figure 3-10 and 3-11). Monthly synoptic data during the operational study period also revealed that surface DO concentrations at Locations 601.0, 603.0, and 605.0 did not fall below 5 mg/l following July 1973 (Figure 3-12). Furthermore, profile data at Locations 601.0 and 603.0 indicated DO concentrations were within the norm for a lake at this latitude. Consequently ONS operations had no effect on the DO regime of Lake Hartwell.

A consistent temporal pattern in dissolved oxygen concentration was observed throughout Lake Keowee over the six year period. Maximum concentrations occurred from January through March. At the onset of thermal stratification, lower bottom waters contained substantial dissolved oxygen concentrations (Figures 3-13 through 3-36). As stratification commenced and these water masses were isolated by density gradients, the lower strata DO concentrations could no longer be regenerated. Consequently, the values decreased due to biological respiration in these lower depths. As previously noted, minimum dissolved oxygen concentrations were observed during August and September. This observation was consistent throughout the lake. However, the intake (509.0) and discharge (508.0) were the only locations to consistently exhibit surface concentrations less than 5 mg/l in August and September following ONS operation. During fall overturn, lake mixing occurred, and dissolved oxygen was replenished to all depths and all sampling locations. Various chemical constituents (iron, manganese, alkalinity, and ammonia) fluctuated inversely with these temporal trends in DO concentration and will be discussed later in this chapter.

The reduction of thermal stratification during the summer, caused by ONS operations, has allowed waters higher in DO concentrations to mix to lower depths. Thus, a lake-wide increase in DO content during the summer has occurred (Figure 3-37). From 1971 through 1975, the month of minimum DO content was September; however, in 1976 this month shifted to August. This shift was due in part to meteorological conditions as well as induced mixing caused by ONS operations. During the winter months, ONS operation has increased lake temperatures resulting in a slight decrease in DO content during this period. Highest DO content, prior to ONS operations, was observed in February. However, from 1974 through 1976, the months of highest DO content were February, March, and January, respectively. This inconsistency in months of highest content could be due to fluctuating meteorological conditions from year to year as well as ONS operations (since a consistent pattern was present prior to ONS operations).

The increase in dissolved oxygen during the summer and slight decrease during the winter is further illustrated in Figures 3-13 through 3-36. In 1974, depletion of dissolved oxygen at the lower depths was more extensive at three deep water locations (501.0, 504.0 and 506.0) than that observed during the preoperational study period. However, during 1975 and 1976 only Locations 501.0 and 504.0 exhibited extensive oxygen depletion at the lower depths. These figures (3-13 through 3-36) also illustrate a diminishing occurrence of waters with dissolved oxygen concentrations greater than 10.0 mg/l during the winter months.

BIOCHEMICAL OXYGEN DEMAND

Biochemical oxygen demand (BOD) measurements were taken on Lake Keowee from January 1971 through December 1976. A total of 626 measurements yielded a mean of 1.1 mg/l with a standard deviation of 0.8 for the study period. The maximum value observed was 9.2 mg/l (Location 507.0; February 1974). However, as reflected by the mean, this was not a typical BOD value for Lake Keowee. Based on a frequency distribution, 54% of the BOD values were less than 1.2 mg/l and 78% of the BOD values were less than 1.8 mg/l. Consequently, BOD is of little significance on Lake Keowee.

Lake Hartwell BOD values were slightly higher than those observed on Lake Keowee as shown by a mean of 1.7 mg/l with a standard deviation of 1.1 for the study period (1971-1976). A frequency distribution of the Lake Hartwell data revealed 47% of the BOD values were less than 1.8 mg/l and 70% of the BOD values fell below 2.2 mg/l. These higher BOD values on Lake Hartwell were attributed to point source discharges to the lake.

pH

The variability of pH values during the study period did not indicate a significant impact of ONS operation on Lake Keowee. Although there was a shift towards lower pH values beginning in 1974, this was attributed to a change from measuring pH in the laboratory to *in situ* measurements. Some increase in pH would be expected to occur with any sample which is held for laboratory analysis (Roberson et al. 1963).

Lake Keowee is slightly acidic with pH values typically ranging between 5.5 and 7.0 (Duke Power Company 1974a, b; 1975a, b; 1976). However, Location 500.0 exhibited slightly higher pH values from May through August in the surface to five meter depth than those observed at Location 506.0 (Figure 3-38 and 3-39). This was attributed to relatively high photosynthetic activity resulting from elevated nutrient concentrations at these depths. The euphotic zone phytoplankton standing crops at Location 500.0 were typically high during the operational period (Chapter 4).

TURBIDITY

Turbidity values throughout the lake were generally below 10 JTU. The highest values were usually recorded in bottom samples. Abnormally high turbidities were a result of the boat drifting into shallower waters during the sampling and the subsequent pumping of muddy water to the surface. These values were not indicative of the turbidities in the water column and often explain higher than normal values for other parameters (i.e. alkalinity, iron, etc.).

MINERAL CONSTITUENTS

General Composition

Lake Keowee drainage basin is composed primarily of metamorphic rock types such as mica (ferromagnesium silicates), hornblende (complex ferromagnesium silicates of aluminum, magnesium, calcium, and sodium), and granite gneiss (potassium, calcium, and sodium silicates) (Johnson et al.). Water associated with these metamorphic rock formations is generally low in solute concentrations and resembles the water from igneous terranes. Although surface water originating in areas where these rock types are found may display the effects of the dissolution of minerals less distinctly than ground waters, various irreversible reactions involving dissolution of their silicates do occur. As a result of the dissolution of these sodium rich minerals common to Keowee basin, the molar concentrations of silica released to the water should be about double that of sodium. Also, higher silica concentrations are expected in relation to total ion content for water originating from granite or rhyolite than for water associated with ultrabasic rock (Hem 1970). White (1957) has reported that high concentrations of bicarbonate, sodium, and relatively low chloride concentrations as compared to total ion content are characteristic of natural waters associated with metamorphic rocks.

Prior to impoundment, the mineral content of the Keowee River was similar to that suggested by White (1957) with silica, bicarbonate, sodium, calcium, and chloride being the major mineral constituents. Molar percentages indicated bicarbonate (29%) was the major ion followed by sodium (16%), calcium (7%), chloride (7%), and magnesium (5%) (Figure 3-40). Silica (31%) was more abundant on the Keowee River than any of the ions measured (Johnson et al. 1968).

The mineral composition of Lake Keowee immediately following impoundment was not evaluated due to lack of complete mineral data (other than iron, manganese, silica, and bicarbonate).

Operational mineral data revealed the composition of Lake Keowee resembled that observed in the Keowee River (Figure 3-40). Major mineral constituents on Lake Keowee were bicarbonate (33%), silica (28%), sodium (14%), calcium (6%), and chloride (6%). Iron and manganese together constituted less than 3% of minerals measured. A slight deficit in the anion-cation balance was observed following impoundment since sulfates were not measured during this period.

Silica

Silica, a major component of the local minerals, showed very little change during the study period. Average annual silica concentrations decreased since impoundment at a rate of 0.1 mg/l-Si each year. This represents a decrease of less than 3% each year. The decrease is attributed to diatom uptake and subsequent sedimentation of diatoms.

Iron and Manganese

The USEPA (1976) has set a limit for iron of 1.0 mg/l for preservation of freshwater life since particulate ferric hydroxides can damage fish gill tissue and ferric oxides form cement-like encasements over fish eggs and bottom dwelling fish food organisms. According to USEPA (1976), manganese is rarely found above 1.0 mg/l in fresh waters and is not yet considered a problem to freshwater aquatic life. However, since iron and manganese possess similar chemical properties, considerable attention was given to these minerals.

Since iron and manganese are allied in their chemical properties, they possessed similar seasonal trends (Figures 3-41 through 3-42). Maximum concentrations occurred in the fall (September-November). Nix (1974) has reported that both cations respond to a decrease in redox potential in anoxic zones of a reservoir during thermal stratification by forming more soluble reduced species. The periods when the maximum concentrations of these two minerals occurred in Lake Keowee were periods when reducing conditions existed at the lower depths. The presence of these anoxic zones in reservoirs causes a breakdown of ferric complexes which result in an increase in bicarbonate, iron, phosphate and silica concentrations (Reid 1961). Operational data revealed significant correlations between iron and alkalinity from ten to twenty meters ($r = 0.59$, $p<.0001$) and twenty meters to bottom ($r = 0.74$, $p<.0001$) (Figure 3-43). This fact, in addition to negligible fluctuations in either silica or phosphate in these regions indicated that iron existed as ferrous bicarbonate complexes at the lower depths of Lake Keowee during anoxic periods. Manganese and alkalinity were also correlated at depths below 10 m ($r = 0.76$, $p<.0001$) indicating manganous bicarbonate complexes also existed at these depths.

During the pre-operational period, highest iron concentrations were observed in the far-field locations with maximum lake-wide concentrations being observed during periods of anoxia (Figure 3-44). Other than the increased concentrations in the late summer and fall, spatial trends were inconsistent during this period. Following ONS operations, maximum concentrations continued to be observed during late summer and fall with the Little River locations exhibiting the maximum concentrations at this time. The near-field and far-field locations showed a slight decline in fall concentrations (Figure 3-44). This concentration decrease was attributed to increased mixing and higher DO trends caused by ONS and Jocassee Pumped Storage operations.

Manganese concentrations, prior to ONS operation, were highest in the Little River locations and corresponded to periods of anoxia in this area (Figure 3-45). Considerable spatial variability in manganese concentrations was observed during this period. Following ONS operation, manganese concentrations decreased throughout the lake with the greatest decrease being observed in the far-field locations. This decrease in concentration was also a result of increased mixing and higher DO levels caused by ONS and Jocassee Pumped Storage operations. However, regardless of this concentration decrease, highest concentrations remained consistent with periods when reducing conditions were present in the bottom waters of the reservoir (Figure 3-42).

Specific Conductance

Specific conductance, a measurement of ionized substances dissolved in water was used by Johnson et al. (1968) as an indicator of dissolved solid content for pre-impoundment data collected on the Keowee River.

Pre-impoundment data collected by Johnson et al. (1968) yielded a mean dissolved solids on Keowee River of 19 mg/l and a mean conductance of 16 micromhos. The average specific conductance for Lake Keowee from 1971 through 1976 was 20 micromhos. Calculated (Hem 1970) mean dissolved solids for this period was 22 mg/l.

Significant correlations were obtained between conductance and iron, ($r = 0.30$, $p<.0001$), manganese ($r = 0.48$, $p<.0001$), ammonia ($r = 0.24$, $p<.0001$), and alkalinity ($r = 0.48$, $p<.0001$). The major spatial differences in specific conductance were observed in the Little River arm. Specific conductance values prior to fall overturn were slightly higher in Little River arm than the lake mean for the period (20 μmhos). This was attributed to hypolimnetic increases of minerals in the Little River arm during this period.

Hardness

According to Hem (1970), soft water can contain a hardness of 0 to 60 mg/l $CaCO_3$;

thus with a mean hardness of 4 mg/l $CaCO_3$, the Keowee River prior to impoundment was classified as a soft water system (Johnson et al. 1968). Since Lake Keowee possessed a mean hardness of 6 mg/l $CaCO_3$ from 1971 through 1976, it was also classified as a soft water system. The similarity in hardness, specific conductance, and mineral concentrations indicated that the source of dissolved material was the same for both Keowee River and Lake Keowee.

AQUATIC NUTRIENTS

"The eutrophication of waters...their enrichment in nutrients and ensuing progressive deterioration of their quality...due to the luxuriant growth of plants...is a problem of increasing urgency in the more highly developed countries. Nitrogen and phosphorus appear to be the most important among the nutrients responsible for eutrophication."

(Vollenweider 1970)

The U. S. Environmental Protection Agency (USEPA) has recommended that discharges to natural waters be controlled to preserve the nitrogen to phosphorus ratio (USEPA 1976). The USEPA (1975) reported a N/P (w/w) ratio of 34 for Lake Keowee. Furthermore, USEPA classified Lake Keowee as mesotrophic and reported no nuisance conditions present during sampling.

Nitrogen to phosphorus ratios computed from operational data yielded data comparable to those obtained by the USEPA. Lowest N/P (w/w) ratios (29) were obtained from the surface to ten meter depth. As depth increased, the ratios increased to a maximum of 44 at the 20 meter to bottom depths. The higher ratios observed at the lower depths were attributed to increased nitrogen concentrations, specifically ammonia. A mean total inorganic nitrogen concentration of 0.226 mg/l-N was calculated for the operational study period. However, ortho-phosphate concentrations were much lower with a mean of 0.008 mg/l-P.

Phosphorus

The phosphorus data revealed a lake-wide decrease in both ortho-phosphate and total phosphorus following the operation of ONS. Analytical methods for ortho-phosphate during pre-operational studies involved the analysis of unfiltered samples which yielded concentrations that were high (0.032 mg/l-P). However, the procedure used during the operational study involved analysis of filtered samples and yielded a mean 0.008 mg/l-P (Figure 3-46). Other than the differences noted from the method change, orthophosphate did not exhibit spatial or temporal variations. Ortho-phosphate comprised between 42% and 54% of the total phosphorus concentrations during the operational study.

Hutchinson (1957) has stated that in most uncontaminated lakes, surface total phosphorus concentrations range from 0.010 to 0.030 mg/l-P. Surface to ten meter phosphorus concentrations were consistently within Hutchinson's range during both pre-operational (0.026 mg/l-P) and operational (0.016 mg/l-P) monitoring.

A steady decrease in total phosphorus has been observed since 1972 (Figure 3-47). This decrease was attributed to the sedimentation of phosphorus as the sediment came to equilibrium with the water. The continued decline in concentration further indicated that phosphorus exchange between the lake and lake sediments had not yet reached equilibrium. This steady decrease has been observed in other newly impounded reservoirs (Weiss 1975).

Seasonal and spatial variations in total phosphorus are illustrated in Figure 3-48. The inconsistency in temporal and spatial variations were attributed to various locations behaving differently during a given month in each year. However, Location 507.0 exhibited the highest overall concentrations of total phosphorus; this was attributed to slight increases in the bottom water during periods of low dissolved oxygen concentrations. Due to the mixing characteristic of the plume, these late summer increases were not observed in the immediate vicinity of ONS. Elevated total phosphorus concentrations were observed at Location 500.0 in January 1975 resulting from an influx of phosphorus near this location.

Nitrogen

As indicated by the N/P ratio, the inorganic nitrogen species occurred in larger quantities than phosphorus in Lake Keowee. A general seasonal pattern in the inorganic nitrogen species was observed throughout the six year study period. Nitrate-nitrite was the dominant form of nitrogen from January through July (Figure 3-49) with maximum concentrations occurring in February and March. These months corresponded to the period when maximum dissolved oxygen concentrations and minimal biological activity were present throughout the lake. Ammonia was the dominant form from August through November. This period corresponded to periods of lowest dissolved oxygen concentrations.

The highest inorganic nitrogen concentrations occurred during 1971 and 1972. These higher concentrations reflect post-impoundment decay of organic material and subsequent leaching of nitrogen from the sediment. Total inorganic nitrogen declined to its lowest concentration in 1974. During 1975 and 1976, the temporal and spatial variability appeared to have stabilized. This phenomenon is typically observed as an impoundment ages (Weiss 1975).

Nitrate-Nitrite

During the pre-operational study period, wide variations in nitrate-nitrite concentrations were observed both temporally and spatially. Maximum concentrations occurred in February (0.321 mg/l). Minimum lake concentrations for the pre-operational study occurred in October and corresponded to periods of lowest dissolved oxygen concentrations. The Little River arm possessed highest nitrate-nitrite concentrations (Figure 3-50). Uplake locations in the Keowee River arm (far-field locations) exhibited the least variability as well as the lowest concentrations. Evaluation of operational data indicated an overall decrease in nitrate-nitrite concentrations after ONS operations began. In addition to the decline in concentration, both spatial and temporal variations in nitrate-nitrite concentrations were less (Figure 3-50). This decrease in concentration and variability between stations and months was attributed to a hydrodynamic phenomenon resulting from induced mixing by ONS operation. Regardless of the decrease in nitrate-nitrite concentrations following ONS operation, the Little River arm continued to exhibit the highest concentrations. This was due to nutrient enrichment as noted in previous data reviews (Duke Power Company 1975a, b; 1976). Far-field locations remained the sites of lowest nitrate-nitrite concentrations. The lower concentrations observed at these locations resulted from dilution with lower nutrient waters from Lake Jocassee which occurred when Jocassee was generating, and mixing of Keowee waters (Federal Power Commission 1977).

As with dissolved oxygen concentrations, ONS operations have caused a temporal shift in nitrate-nitrite peaks. Although winter continued to be period of maximum nitrate-nitrite concentrations, the peak shifted from February to March (Figure 3-50). The months of lowest concentrations also shifted from October and November (pre-operation) to September and October (operational). These peak shifts were related to periods of maximum and minimum dissolved oxygen concentrations in the reservoir.

Ammonia

Seasonal fluctuations in pre-operational ammonia concentrations were inversely correlated ($r = -0.42$, $p<0.0001$) with dissolved oxygen concentrations in Lake Keowee. Thus, minimum concentrations occurred in April and maximum concentrations occurred in September and November. These fall peaks were a function of hypolimnetic ammonia increases (Figure 3-51). Typically, these increases in concentrations are due to increased biodegradation and a decrease in the oxidation state at the sediment-water interface (Wetzel 1975).

Far-field locations exhibited the highest ammonia concentrations during pre-operational monitoring (Figure 3-52); near-field locations exhibited the lowest ammonia concentrations. Wide spatial and temporal variability existed prior to ONS operation (Figure 3-52).

Operation of ONS resulted in an overall decrease in ammonia concentration, stabilization of spatial variability and shifting of periods of maximum concentration. Lowest concentrations continued to be observed in April. However, in the fall, maximum concentrations shifted from September and November (pre-operational) to August and Ocotber (operational). The spring decrease was associated with circulation patterns which occurred prior to stratified periods. The late summer and early fall concentration elevations were also related to dissolved oxygen concentrations and accompanying lowered redox potentials in the lower depths of the reservoir (Figure 3-51). The decrease in spatial and temporal variability (Figure 3-52) from January through May indicated a stabilizing trend which resulted from induced mixing of Lake Keowee by ONS and Jocassee Pumped Storage operations.

HEAVY METALS

Heavy metals are typically referred to as those elements which have a specific gravity greater than four and occur in concentrations less than one milligram per liter (Brown 1976). In this study, the heavy metals included cadmium, chromium, copper, mercury, nickel, and zinc. Aluminum, often classified as a light metal, might also have been included in the list. However, since aluminum is more common to the geology of this area than other areas of the country, it was discussed as a minor mineral constituent.

Buhler (1973) cited five reasons of concern for heavy metals in the environment:

1) These elements are widely distributed throughout the environment;
2) They are not degraded and hence persist in nature for extended periods of time;

3) They are generally toxic to living organisms at fairly low concentrations;
4) They tend to bioaccumulate in plants and animals; and
5) Certain metals can be converted to more toxic forms in the environment.

The USEPA has set forth guidelines for those inorganic "substances which may occur in water where data indicates the potential for harm to aquatic life or to water users or consumers of the water or [consumers of] aquatic life". Consequently, although heavy metals were not included in the ETS, it was deemed necessary by Duke Power Company personnel to monitor the occurrence of each of the above mentioned heavy metals in Lake Keowee and from this monitoring, to determine if their concentrations in Lake Keowee were detrimental.

Cadmium concentrations in Lake Keowee (Figure 3-53) were generally below the 0.4 μg/l limit set by the USEPA (1976) for soft water systems. However, during the fall of 1973 each area of the lake exhibited concentrations in excess of 0.4 μg/l. Each year following 1973, increased concentrations were observed in the fall but not to the extent observed in 1973. As with iron and manganese, these elevated fall concentrations were also indicative of changes in redox potentials at the sediment water interface prior to fall overturn. In the presence of either bicarbonate or carbonate, cadmium rapidly forms soluble carbonate complexes (Rubin 1974) thus, the increases in cadmium were associated with increases in alkalinity observed at the same time. This was probably the mechanism of cadmium release from the sediment. As discussed previously, iron and manganese also appeared to complex with the bicarbonate-carbonate species.

Copper concentrations in Lake Keowee (Figure 3-54) were well below the recommended USEPA limits for domestic water supply (1 mg/l). Literature (USEPA 1976) reports that 80 μg/l-Cu could produce acute toxicity (96 hr TL_{50}) to bluegill. The test waters were similar in hardness, alkalinity and pH to Lake Keowee. Although maximum copper concentrations, as with cadmium, were observed in the fall of each year, these values were well below those recommended as harmful to bluegill. The higher fall concentrations were attributed to $CuCO_3$ complexes resulting from increased alkalinity also observed at this time. These soluble copper complexes were the result of lower oxidation-reduction potentials at the lower depths allowing copper to solubilize from the sediment into the water column. These $CuCO_3$ complexes have been found to be much less toxic than the cupric ion (Andrews 1976). Copper concentrations decreased considerably following turnover (Figure 3-54).

The near-field locations generally exhibited highest copper concentrations. However, the single highest concentration (550 μg/l) was recorded at Location 549.0 in August 1975. This concentration was associated with hydro operations at Jocassee Pumped Storage Station. Higher metal concentrations could be the result of increased turbidity associated with hydro operations.

Chromium and nickel were well below the USEPA limits of 300 and 100 μg/l, respectively. Neither metal displayed significant spatial or temporal trends.

Various authors have reported zinc toxicity levels ranging from 0.01 through 2.00 mg/l depending on species, duration of exposure and quality of water used as a test environment (Buhler 1973). For waters with similar pH, hardness and alkalinity as Lake Keowee a 96 hour TL_{50} for bluegill was reported at 2.58 mg/l (USEPA 1976). Reported zinc values for Lake Keowee never exceeded

0.35 mg/l. A mean of 0.033 mg/l indicated that zinc concentrations were sufficiently below the USEPA limit. Seasonal variations in zinc concentrations were inconsistent; however, lake concentrations were higher in 1973 and 1974 than those observed in the following years. The Little River arm exhibited the highest overall concentrations (Figure 3-55).

Mercury concentrations in Lake Keowee from 1974 through 1976 were consistently less than 0.1 μg/l. A single high value (0.6 μg/l) was reported for Location 501.0 in February 1976. Concentrations reported to produce toxicity in various fish species range from 0.005 to 0.2 mg/l (Buhler 1973). The USEPA (1976) has set a limit of 0.05 μg/l for preservation of freshwater life.

Heavy metals monitored were usually below toxic levels set by the USEPA. Only cadmium and copper exhibited seasonal trends with highest concentrations occurring in the fall. Operation of ONS did not appear to have any effect on heavy metal concentrations in Lake Keowee.

SUMMARY AND CONCLUSIONS

Water chemistry of Lake Keowee was monitored at monthly intervals from January 1971 through December 1976. Examination of the data revealed that anoxic conditions existed in the hypolimnion during late summer accompanied by increased ammonia, iron, manganese, and alkalinity. Operation of ONS has resulted in a shift of the anoxic period from fall to late summer and a general change in the dissolved oxygen regime of the lake. Prior to ONS operation, runoff was the primary factor influencing the water chemistry of the top ten meters of the lake. Following ONS operation, the thermal regime became the primary factor influencing the chemical variations in these waters. The chemistry of the bottom waters (20 m to bottom) of Lake Keowee did not appear to be affected by ONS operation.

Operation of ONS resulted in low surface dissolved oxygen concentrations (<5.0 mg/l) over only 0.4% of the lake. These values were restricted to the immediate discharge area of ONS. Furthermore, this condition was restricted to late summer or early fall. After overturn, all effects of summer anoxia were dissipated. Weekly and monthly monitoring indicated that ONS operations had no effect on the dissolved oxygen regime or water chemistry of Lake Hartwell.

Seventy-eight percent of the biochemical oxygen demand concentrations obtained from Lake Keowee were below 1.8 mg/l. This parameter showed no appreciable spatial or temporal fluctuations. Lake Hartwell biochemical oxygen demand concentrations were slightly higher than Lake Keowee with 70% of the values falling below 2.2 mg/l. The slightly higher values observed on Lake Hartwell were attributed to point source discharges to the lake. Moreover, BOD concentrations from either Lake Keowee or Lake Hartwell showed little change following ONS operation.

ONS operations did not appreciably affect the mineral composition of Lake Keowee. The mineral composition during ONS operation was similar to the composition of the Keowee River prior to impoundment. Iron and manganese, however, exhibited much less variability after ONS operations began than before operation. This stabilization was the result of induced mixing by ONS and Jocassee Pumped Storage operations.

Inorganic N/P ratios calculated from monitoring data were in agreement with EPA N/P ratios calculated from studies in 1973 on the lake. EPA reported Lake Keowee to be a phosphorus-limited system. Correlation analyses revealed variations in the N/P ratio were a function of variations in inorganic nitrogen, primarily ammonia. A continued decrease in lake-wide total phosphorus concentrations was observed since impoundment. The initial concentrations (1971-72) were the result of sediment release of phosphorus after impoundment. The continual decrease indicates that Lake Keowee has not yet reached equilibrium with respect to total phosphorus. Operation of ONS has had no apparent effect on this decrease. Spatial and temporal variations of all nutrients have stabilized as a result of ONS operation. Concentrations of aquatic nutrients have also shown a slight decrease following ONS operations. In general, the availability of nutrients has decreased since the start of ONS operation. In particular, total phosphorus had decreased 66% since impoundment; this decrease is still continuing.

Operation of ONS had no effect on heavy metals concentrations. Copper and cadmium concentrations displayed increased levels in the fall in response to changes in oxidation-reduction levels. Chromium, lead, nickel, and zinc concentrations were below toxic levels. These metals did not display any seasonal trends.

Based on monitoring data from 1971 through 1976 the major impacts of ONS operations on the water chemistry of Lake Keowee were a shift in the date of chemical overturn, from November to October, stabilization of nutrient variations and increased mixing of the lake throughout the operational study period. These impacts are all the result of the pumping component rather than the thermal component of ONS operations.

RECOMMENDATIONS

Based on the above conclusions the following recommendations are submitted:

1) Since water chemistry parameters display well defined seasonal patterns, sampling frequency should be reduced to six times per year and confined to the locations and parameters listed in Table 1.0-1 (Specification 1.3.1-A) except as noted below.

2) Since biochemical oxygen demand values obtained from either Lake Keowee or Lake Hartwell were insignificant and showed little seasonal or spatial variability, the analyses of this parameter should be discontinued from both systems (Specification 1.3.1-A).

3) Since ONS operations have had no effect on Lake Hartwell water chemistry, monitoring of Lake Hartwell should be restricted to Location 605.0 (Specification 1.3.1-A).

4) Although no requirements exist for analyses of heavy metals, a number of heavy metals were measured. Since only cadmium and copper displayed

occasional concentrations above toxic levels, heavy metal analyses should be confined to these two parameters.

5) Since low plume DO concentrations were observed only at ONS discharge structure, weekly monitoring of dissolved oxygen should be limited to the intake and discharge structure and confined to August and September (Specification 1.3.1-A).

6) Since the occurrence of low surface dissolved oxygen concentration (<5.0 mg/1) is restricted to the immediate discharge area, dissolved oxygen plume studies should be discontinued (Specification 1.6).

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1975 Jan-Jun Jul-Dec 1976 Jan-Jun Jul-Dec

Table 3-2. Analytical methods, preservatives, references and detection limits for chemical and physical parameters sampled on Lake Keowee from 1971 through 1976.

Parameter	Method	Preservative	Reference	Detection Limit
Alkalinity, total	Method 102	4C	A.P.H.A. et. al. 1971	1 mg/l-$CaCO_3$
Aluminum, total	Atomic Absorption/DA	0.5% HNO_3	Perkin-Elmer Corp. 1973 a,b	1.0 mg/l
	Atomic Absorption/HGA			0.03 μg/l
Ammonia	Method 132	4C	A.P.H.A. et.al. 1971	0.01 mg/l
	Gas diffusion electrode	4C	Orion Research	0.014 mg/l-N
	Method 98-70W	4C, filtration	Technicon Ind. Systems 1972	0.005 mg/l-N
	Method 329-74 W/A	4C, filtration	Technicon Ind. Systems 1972	0.008 mg/l-N
Biochemical Oxygen Demand $(BOD)_{14}$	Method 219	4C	A.P.H.A et.al. 1971	0.5 mg/l
Cadmium, total	Atomic Absorption/HGA	0.5% HNO_3	Perkin-Elmer Corp. 1973b	0.1 μg/l
Calcium, total	Atomic Absorption/DA	0.5% HNO_3	Perkin-Elmer Corp. 1973a	0.01 mg/l
Chloride	Method 112A	None required	A.P.H.A. et.al. 1971	0.5 mg/l
	Specific ion electrode	None required	Orion Research Inc. 1970	0.35 mg/l
	Method 99-70W	4C, filtration	Technicon Ind. Systems 1972	0.3 mg/l
Chromium, total	Atomic Absorption/HGA	0.5% HNO_3	Perkin-Elmer Corp. 1973b	0.5 μg/l
Conductance, specific	Method 154	None required	A.P.H.A. et.al. 1971	1 μmhos/cm
	temperature compensated nickel electrode	In Situ	Hydrolab Corp. 1973	1 μmhos/cm
Copper, total	Atomic Absorption/DA	0.5% HNO_3	Perkin-Elmer Corp. 1973a	0.1 mg/l
	Atomic Absorption/HGA	0.5% HNO_3	Perkin-Elmer Corp. 1973b	0.01 μg/l
Dissolved Oxygen	Method 218B	In Situ (pumped sample)	A.P.H.A. et.al. 1971	0.1 mg/l
	Temperature Compensated Polarographic cell	In Situ	Hydrolab Corp. 1971	0.1 mg/l
1% Incident light	Photometer	In Situ	Montedoro-Whitney Corp. 1974	0.5 m
Iron, total	Method 124A		A.P.H.A. et.al. 1971	0.01 mg/l
	Atomic Absorption/DA	0.5% HNO_3	Perkin-Elmer Corp. 1973	0.01 mg/l
Magnesium, total	Atomic Absorption/DA	0.5% HNO_3	Perkin-Elmer Corp. 1973	0.01 mg/l
Light Penetration	Secchi disc	In Situ	Welch 1948	
Manganese, total	Method 128C		A.P.H.A. et.al. 1971	0.01 mg/l
	Atomic Absorption/DA	0.5% HNO_3	Perkin-Elmer Corp. 1973a	0.01 mg/l
Mercury, total	Atomic Absorption/Method 71900	1.0% HNO_3	Perkin-Elmer Corp. 1973a U.S.E.P.A. 1973	0.1 μg/l

Table 3-2 (Cont.)

Parameter	Method	Preservative	Reference	Detection Limit
Nickel, total	Atomic Absorption/ HGA	0.5% HNO_3	Perkin-Elmer Corp. 1973 b	10 ug/l
Nitrite-Nitrate	Method 213C	4C	A.P.H.A. et.al. 1971	0.01 mg/l
	Method 158-71W	4C, filtration	Technicon Ind. Systems 1972	0.02 mg/l
Orthophosphate, soluble	Method 223F	4C	A.P.H.A. et.al. 1971	0.03 mg/l
	Method 155-71W	4C, filtration	Technicon Ind. Systems 1972	0.005 mg/l
Oxidation-Reduction Potential	Hydrolab Surveyor 6-D	*In situ*	Hydrolab Corp., 1971	-1000 mv
pH	temperature compensated glass electrode/Method 144A		A.P.H.A. et. al. 1971	0.1
	temperature compensated glass electrode	*In Situ*	Hydrolab Corp. 1971	0.1
Phosphorus, total	Persulfate Digestion/Method 223F	4C	A.P.H.A. et.al. 1971	0.03 mg/l
	Method 00665	4C	U.S.E.P.A. 1974	0.005 mg/l
Potassium, total	Atomic Absorption/DA	0.5% HNO_3	Perkin-Elmer Corp. 1973a	0.1 mg/l
Silica, soluble	Method 151B	4C	A.P.H.A. et.al. 1971	0.1 mg/l
	Method 105-71W	4C	Technicon Ind. Systems 1972	0.02 mg/l Si
Sodium, total	Atomic Absorption/DA	0.5% HNO_3	Perkin-Elmer Corp. 1973a	0.1 mg/l
Surface illumination	Photometer	*In Situ*	Montedoro-Whitney Corp. 1974	0.01 ly/min
Temperature	Method 162 thermistor-thermometer	*In Situ*	A.P.H.A. et. al. 1971	0.5 F
	Thermistor-thermometer	*In Situ*	Hydrolab Corp. 1971	0.25 C
Turbidity	Lumetron Mod. 450	4C	Photovolt Corp. 1959	1 JTU
	Monitek Turbidimeter	4C	Monitek Tech., Inc. 1973	1 JTU
Zinc, total	Atomic Absorption/DA	0.5% HNO_3	Perkin-Elmer Corp. 1973	10 ug/l
	Atomic Absorption/HGA		Perkin-Elmer Corp. 1973	.2 ug/l

Table 3-3. Changes in analytical methods and the periods when the methods were employed.

Parameter	Method	Reference	Period Used
Ammonia	Method 132	A.P.H.A. et.al. 1971	1/1971 - 7/1973
	Gas diffusion electrode	Orion Research Inc. 1972	8/1973 - 7/1974
	Method 98-70W	Technicon Ind. Systems. 1972	7/1974 - 12/1976
	Method 320-74 W/A	Technicon Ind. Systems 1976	2/76 - 12/76
Chloride	Method 112A	A.P.H.A. et.al. 1971.	1/1971 - 7/1973
	Specific ion electrode	Orion Research Inc. 1970	8/1973 - 6/1976
	Method 99-70W	Technicon Ind. Systems. 1972	7/1975 - 12/1976
Conductance specific	Method 154	A.P.H.A. et.al. 1971	1/1971 - 7/1973
	Temperature compensated Nickel electrode	Hydrolab Corp. 1973	8/1973 - 12/1976
Dissolved Oxygen	Method 218B	A.P.H.A. et.al. 1971	1/1971 - 7/1973
	Temperature compensated Polargraphic cell	Hydrolab Corp. 1973	8/1973 - 12/1976
Iron, total	Method 124A	A.P.H.A. et.al. 1971	1/1971 - 7/1973
	Atomic Absorption/DA	Perkin-Elmer Corp. 1973	8/1973 - 12/1976
Manganese, total	Method 128C	A.P.H.A. et.al. 1971	1/1971 - 7/1973
	Atomic Absorption/DA	Perkin-Elmer Corp. 1973	8/1973 - 12/1976
Nitrite - Nitrate	Method 213C	A.P.H.A. et.al. 1971	1/1971 - 7/1973
	Method 158-71W	Technicon Ind. Systems. 1972	8/1973 - 12/1976
Orthophosphate, soluble	Method 223F	A.P.H.A. et.al. 1971	1/1971 - 7/1973
	Method 155-71W	Technicon Ind. Systems. 1972	8/1973 - 12/1976
pH	Temperature compensated glass electrode/Method 144A	A.P.H.A. et.al. 1971	1/1971 - 7/1973
	Temperature compensated glass electrode	Hydrolab Corp. 1971	8/1973 - 12/1976
Phosphorus, total	Persulfate Digestion/Method 223F	A.P.H.A. et.al. 1971	1/1971 - 7/1973
	Method 00665	U.S.E.P.A. 1974	8/1973 - 12/1976
Silica, soluble	Method 151B	A.P.H.A. et.al. 1971	1/1971 - 7/1973
	Method 105-71W	Technicon Ind. Systems. 1972	8/1973 - 12/1976
Temperature	Thermistor-thermometer	A.P.H.A. et.al. 1971	1/1971 - 7/1973
	Thermistor-thermometer	Hydrolab Corp. 1971	8/1973 - 12/1976
Turbidity	Lumetron Model 450	Photovolt Corp. 1959	1/1971 - 7/1973
	Monitek Turbidimeter	Monitek Tech., Inc. 1973	8/1973 - 12/1976

Table 3-4 Dominant factors in order of importance in designated portions of the water column of Lake Keowee

Period	Depth	Parameter	Inferred Factor Name	Percent Variation Explained
Pre-operational	≤10 meters	Turbidity Ortho-phosphate Total Phosphorus Iron	Runoff	43
		pH Nitrate-nitrite Silica	Biological Activity	30
Pre-operational	>20 meters	Nitrate-nitrite Ortho-phosphate Total Phosphorus	Nutrients	47
		Temperature Alkalinity Ammonia Dissolved oxygen	Thermal Regime	32
Operational	≤10 meters	Temperature Dissolved oxygen pH	Thermal Regime	33
		Conductivity Silica	Minerals	20
Operational	10-20 meters	Manganese Iron Alkalinity	Oxidation-reduction potential	44
		Temperature Dissolved oxygen pH	Thermal Regime	22
Operational	>20 meters	Conductivity Alkalinity Ammonia Iron Manganese	Oxidation-reduction potential	53
		Temperature Dissolved oxygen pH	Thermal regime	18

Table 3-5. Summary of weekly dissolved oxygen monitoring dissolved oxygen values in mg/l, April through November, 1973 through 1976.

	April			May			'une			July			August			September			October			November		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Oconee Intake																								
1974	8.3	8.2	8.2	8.0	7.0	7.4	6.7	5.6	6.2	6.4	4.5	5.4	4.7	3.9	4.2	5.1	3.4	3.9	7.1	5.3	6.4	8.3	6.8	7.6
1975	10.0	8.6	9.2	8.9	7.0	7.8	6.7	6.0	6.3	5.8	4.9	5.4	6.0	4.0	4.5	5.9	3.6	4.8	6.8	5.9	6.5	8.3	6.6	7.4
1976				7.9	7.3	7.5	7.0	6.2	6.5	6.3	4.8	5.5	4.7	4.2	4.4	5.9	4.8	5.4	7.7	5.9	6.8	9.0	7.7	8.4
Oconee Discharge																								
1973							8.4	7.6	7.9	12.0	10.0	11.0	10.3	7.4	8.6	8.1	2.8	4.9	4.7	2.2	3.4	9.0	6.9	7.7
1974	8.7	8.4	8.6	8.8	7.4	8.3	7.2	6.0	6.2	7.8	4.8	5.9	5.6	4.4	4.8	5.2	3.4	4.2	7.0	5.4	6.3	8.2	7.0	7.6
1975	10.0	8.7	9.3	9.6	7.1	8.0	6.7	6.2	6.3	6.3	5.5	5.9	5.3	4.4	4.7	5.8	3.8	4.9	7.1	6.0	6.6	8.7	7.0	7.7
1976				8.9	8.2	8.5	7.4	6.4	6.8	7.8	5.1	5.9	4.8	4.3	4.6	6.0	5.0	5.5	7.4	5.9	6.6	8.7	7.6	8.2
Keowee Intake																								
1973							8.4	7.9	8.2	13.0	12.0	12.5	11.6	8.0	9.3	7.4	6.5	6.9	5.5	3.6	4.8	7.9	6.3	7.4
1974	9.2	8.9	9.0	8.9	8.4	8.6	8.4	7.3	7.8	8.5	6.8	7.8	8.4	6.1	7.1	5.8	4.4	5.3	7.2	6.0	6.7	8.0	7.0	7.6
1975	9.7	8.6	9.2	9.4	7.1	8.6	7.7	6.8	7.2	7.8	5.9	6.7	6.2	5.3	5.6	6.4	5.0	5.6	7.2	6.2	6.7	8.7	7.2	7.6
1976				8.6	8.3	8.4	7.8	7.6	7.7	7.7	6.7	7.3	6.0	5.2	5.6	6.4	5.8	6.1	7.3	6.5	6.8	9.0	7.5	8.2
Keowee Discharge																								
1973							8.9	8.2	8.6	15.3	12.0	13.6	9.7	6.8	7.8	7.8	7.3	7.6	6.8	5.4	6.4	9.3	7.4	8.0
1974	9.6	9.0	9.3	9.6	8.3	8.9	9.2	7.5	8.4	8.5	6.1	7.7	6.6	5.5	5.9	6.7	5.4	6.2	7.9	7.3	7.5	8.7	8.1	8.3
1975	9.7	9.6	9.6	9.8	8.0	8.7	8.2	7.6	7.8	8.1	6.6	7.3	7.6	6.3	6.7	8.2	6.6	7.2	8.8	6.5	7.4	9.5	7.6	8.4
1976				9.8	8.7	9.2	8.4	7.3	7.8	9.2	6.3	7.3	7.4	6.5	6.9	7.9	5.9	7.3	8.2	7.0	7.5	9.6	7.7	8.6
Station 605																								
1974				9.2	8.3	8.8	9.4	7.8	8.5	8.2	5.9	7.4	6.8	5.8	6.4	6.9	5.6	6.3	8.6	7.3	7.8	9.3	8.0	8.4
1975	10.0	9.6	9.8	10.7	8.0	9.3	8.0	7.6	7.8	8.4	6.5	7.2	7.1	6.2	6.6	7.6	6.6	7.0	8.2	6.4	7.3	9.3	7.4	8.3
1976				9.9	8.6	9.4	8.6	6.9	7.7	9.0	6.0	7.3	7.5	6.6	6.9	7.8	5.9	7.2	8.1	7.3	7.7	9.6	7.7	8.9

Table 3-6. Comparison of Predicted and Observed Surface Areas Affected by CCW Discharge.

Dissolved Oxygen (mg/1)	Predicted Percentages of total surface area		Observed Percentages of total surface area				
	Normal Conditions	Extreme Conditions	8/13/75	8/14/75	9/10/75	9/1/76	9/15/76
<1	0.5	0.5					
<2	3.8	3.8					
<3	6.5	6.5					
<4	11.4	16.3					
<5	16.3	27.8	0.1	0.1	0.4	<0.1	<0.1
<6			10.0	6.6	7.5	9.3	0.1
<7			23.3	13.8			26.1

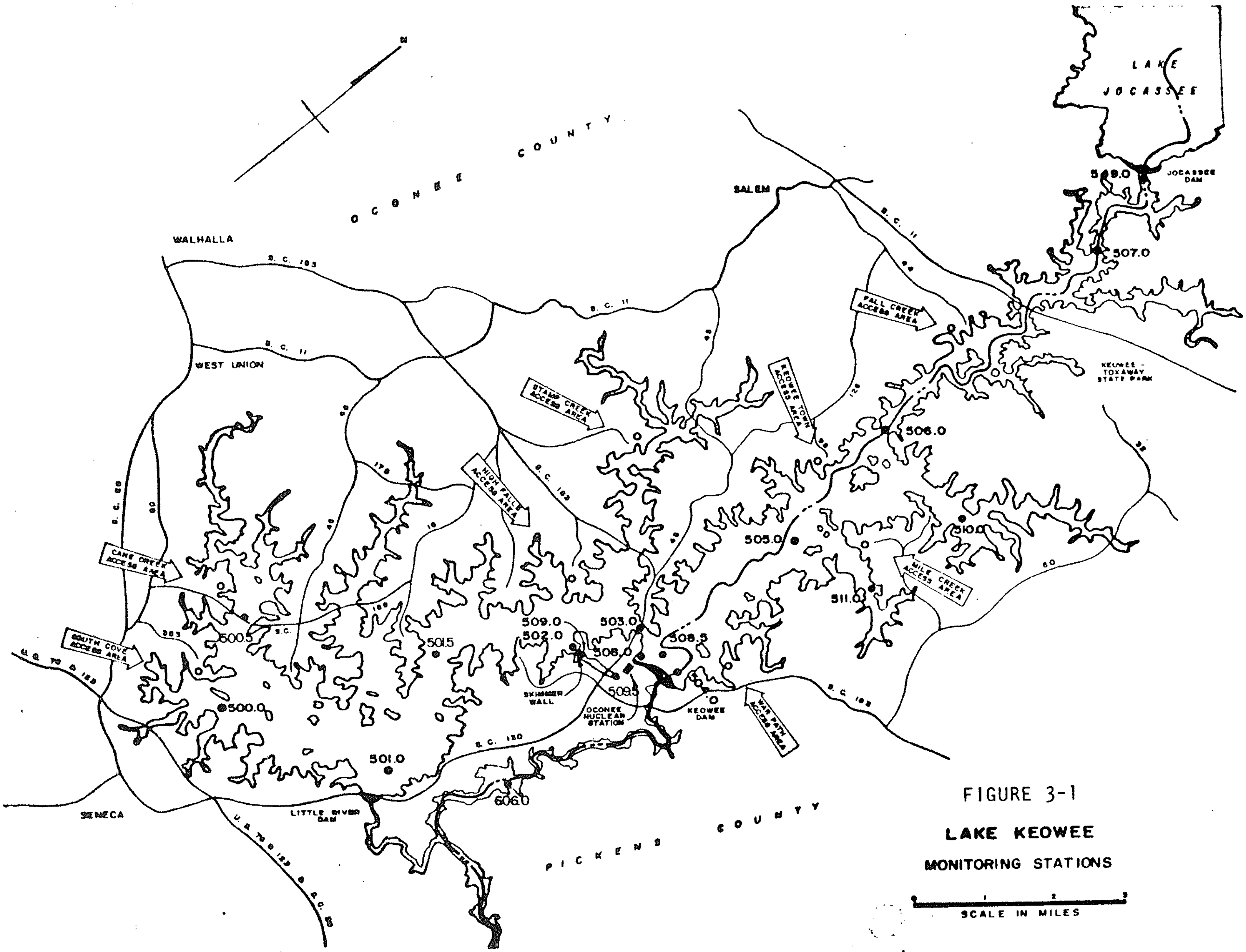


FIGURE 3-1

LAKE KEOWEE

MONITORING STATIONS

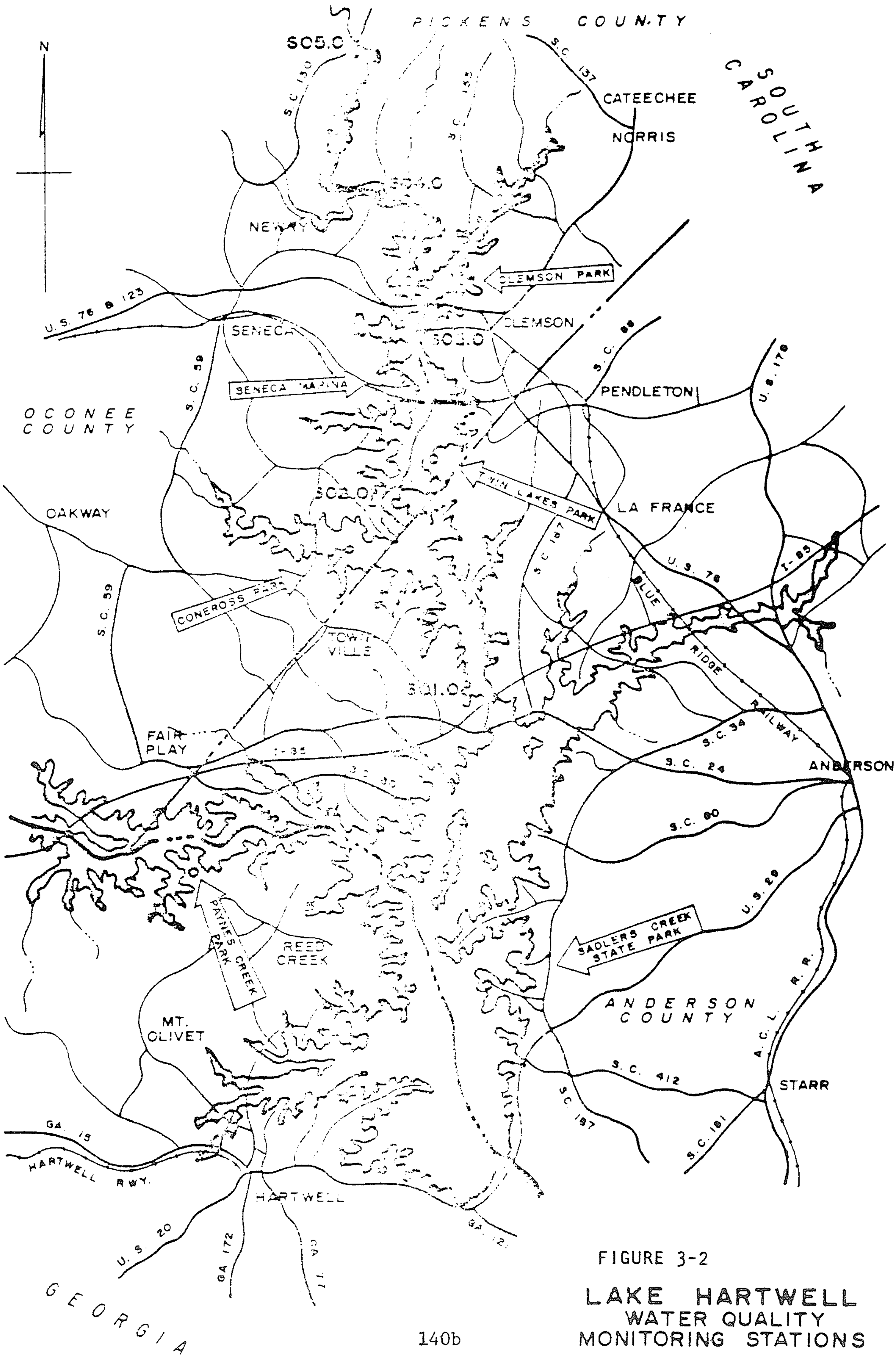


FIGURE 3-2

LAKE HARTWELL
WATER QUALITY
MONITORING STATIONS

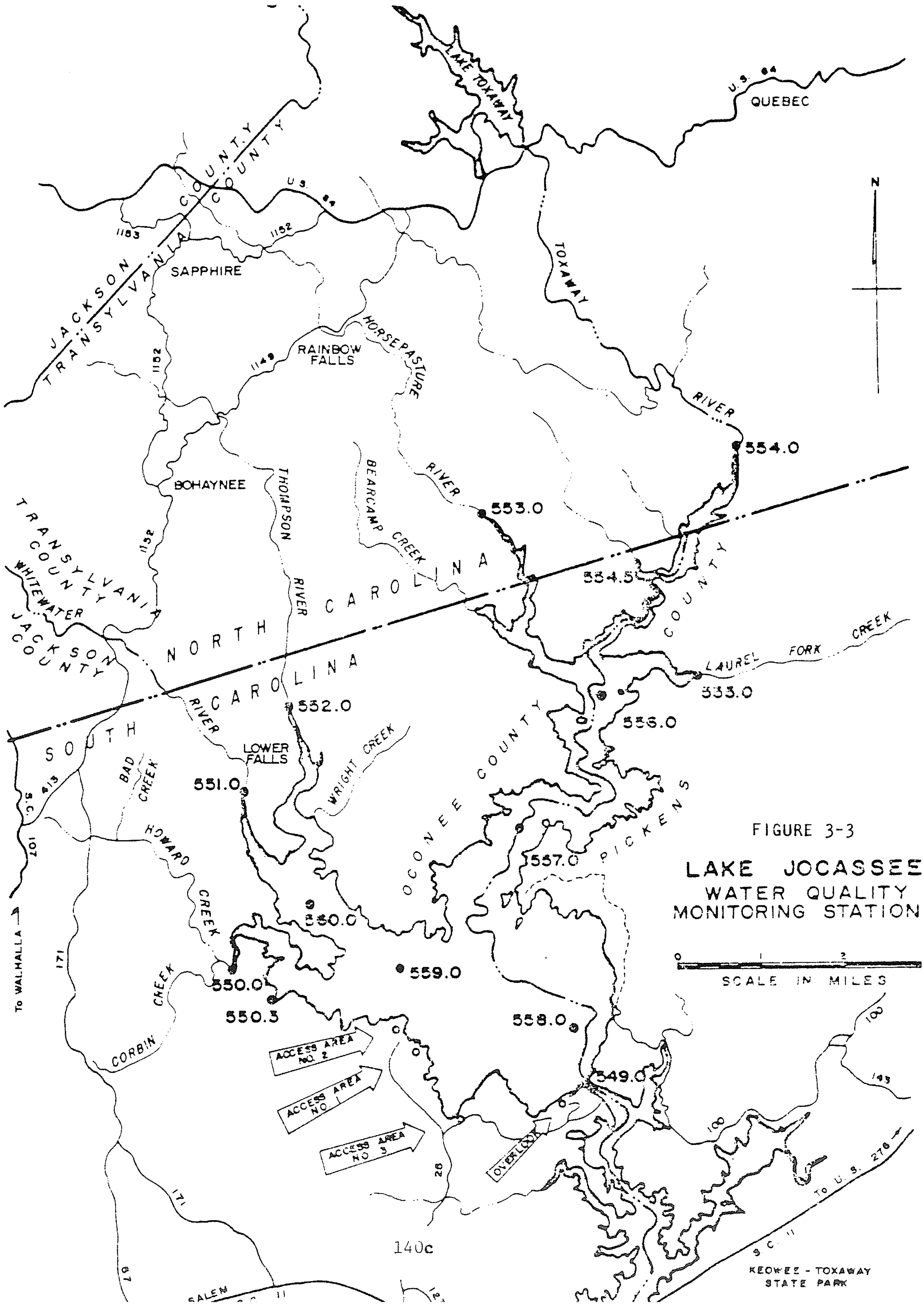


FIGURE 3-3

LAKE JOCASSEE WATER QUALITY MONITORING STATION

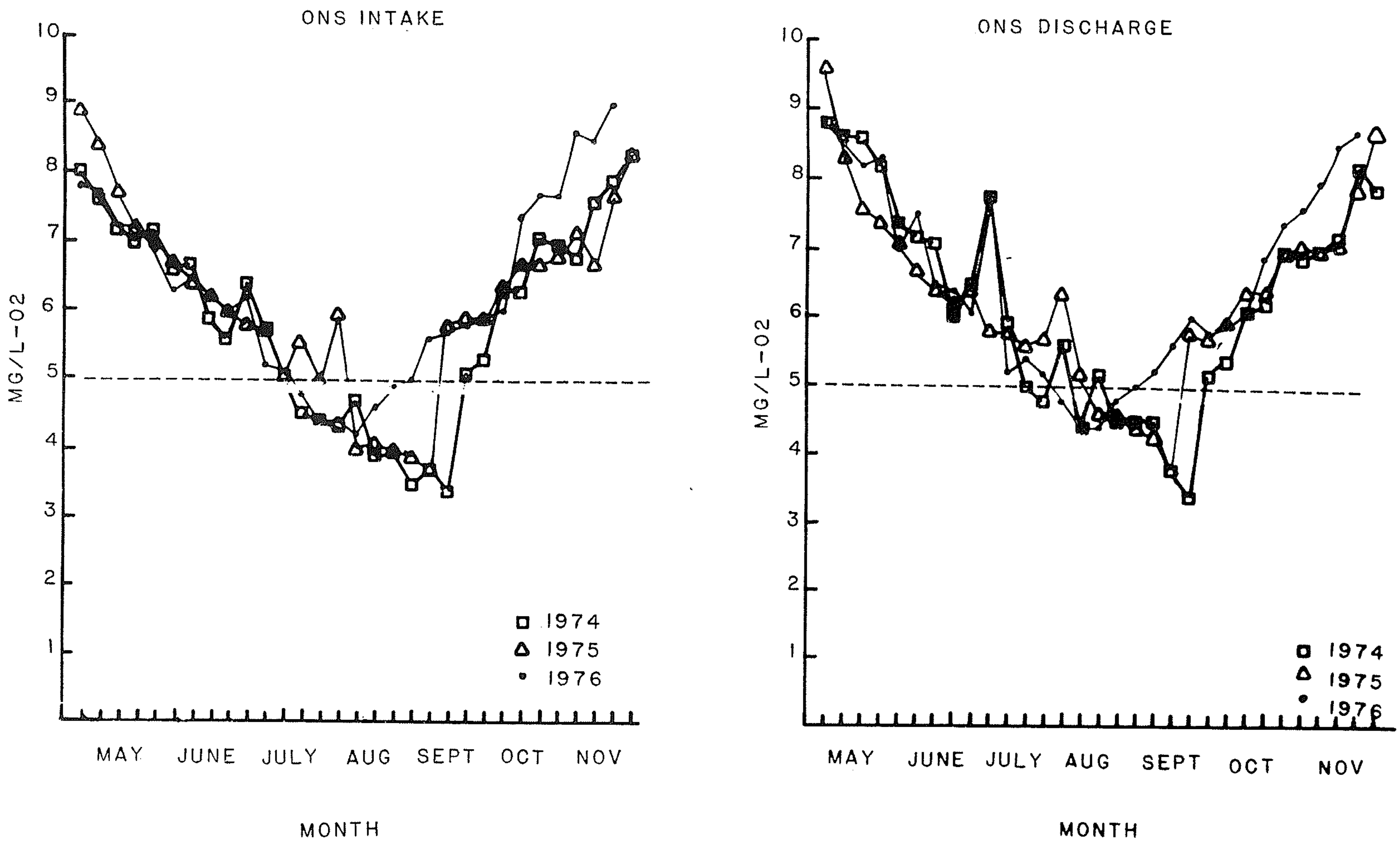
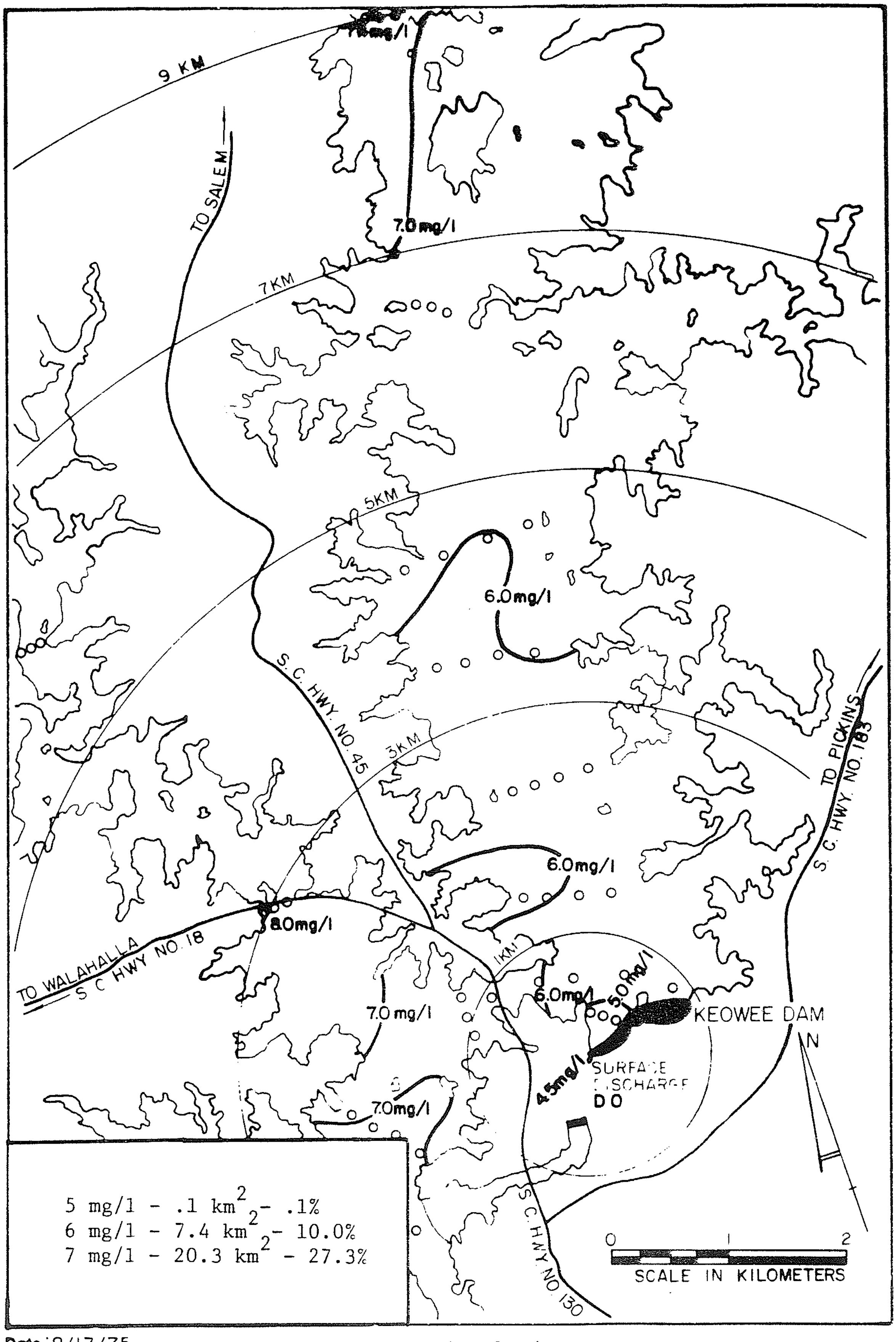


Figure 3-4. Weekly dissolved oxygen concentrations at ONS intake and ONS discharge structure from May through November from 1974 through 1976.

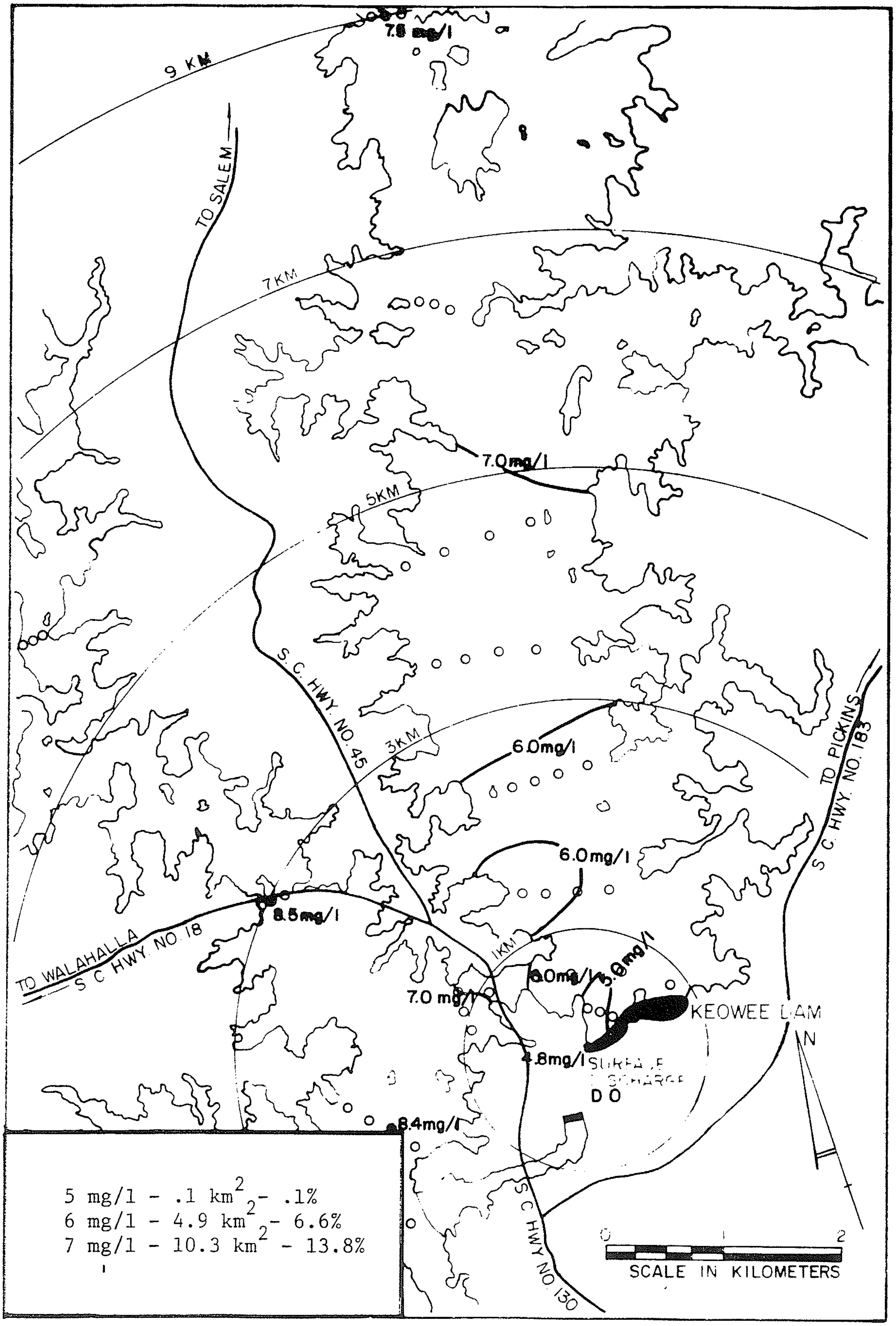


5 mg/l - .1 km^2 - .1%
6 mg/l - 7.4 km^2 - 10.0%
7 mg/l - 20.3 km^2 - 27.3%

Date: 8/13/75

Oconee Nuclear Station
Plume Mapping Study
Surface D O (mg/l)

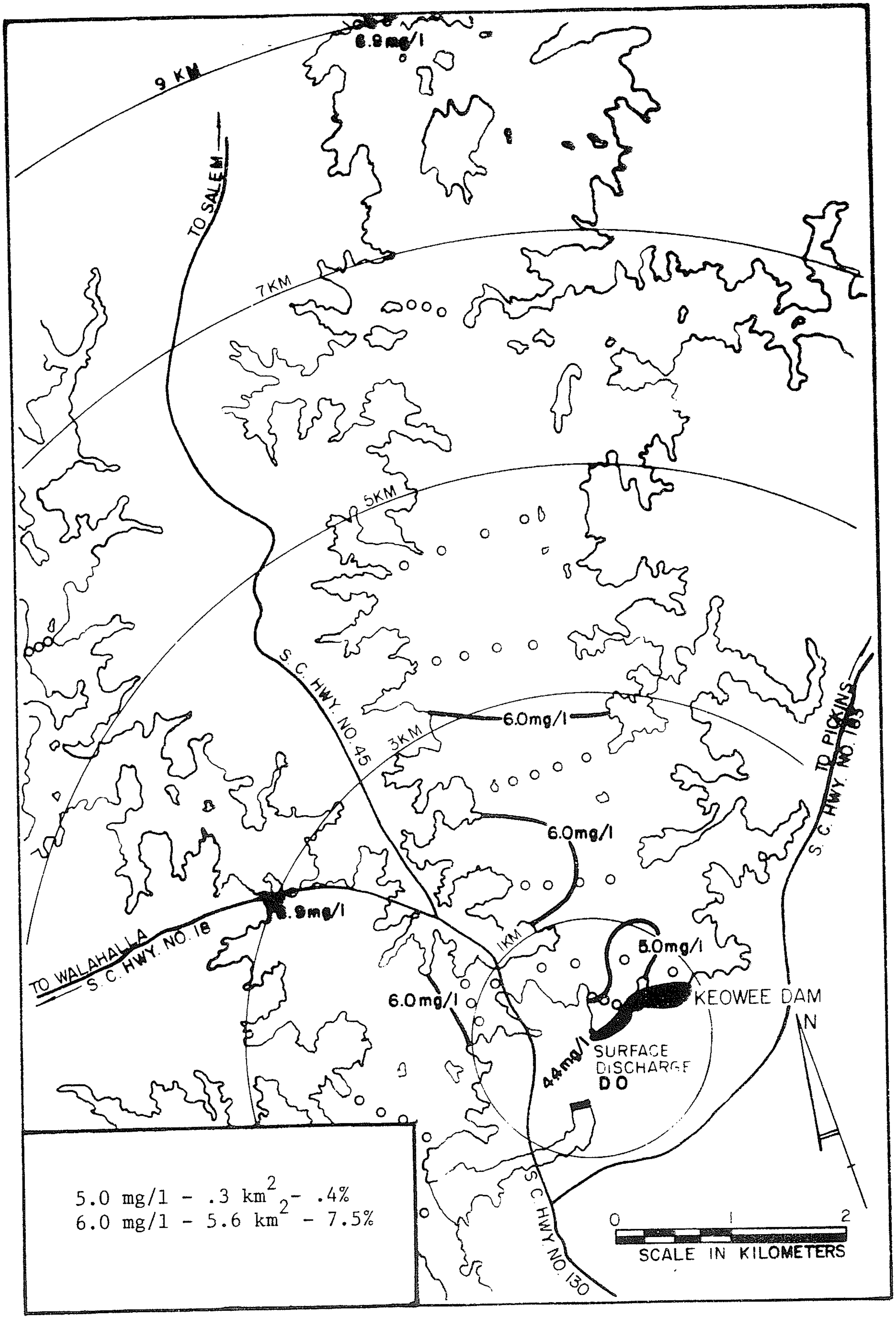
Figure: 3-5



Date: 8/14/75

Oconee Nuclear Station
Plume Mapping Study
Surface D O (mg/l)

Figure: 3-6

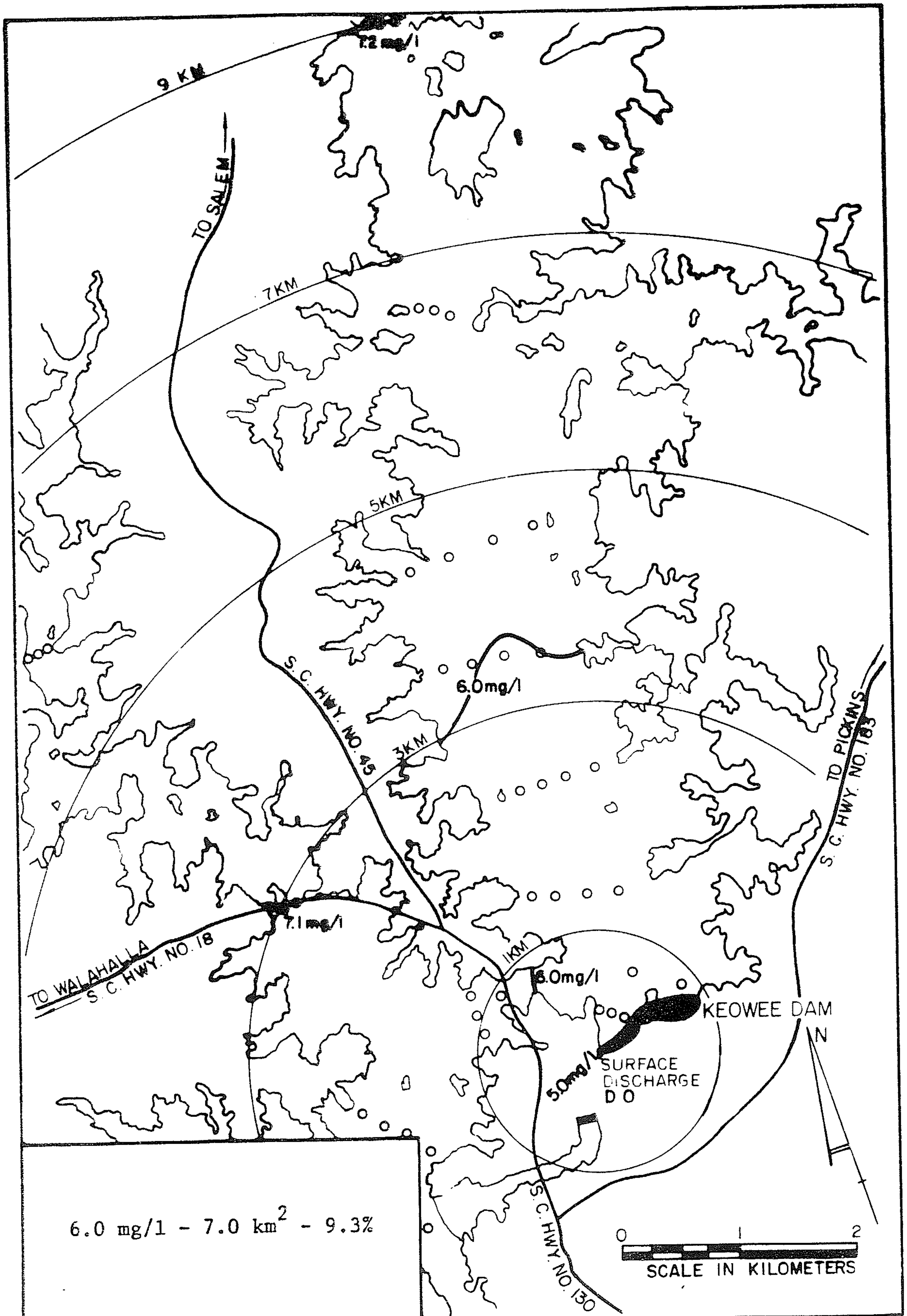


5.0 mg/l - .3 km^2 - .4%
6.0 mg/l - 5.6 km^2 - 7.5%

Date: 9/10/75

Oconee Nuclear Station
Plume Mapping Study
Surface D O (mg/l)

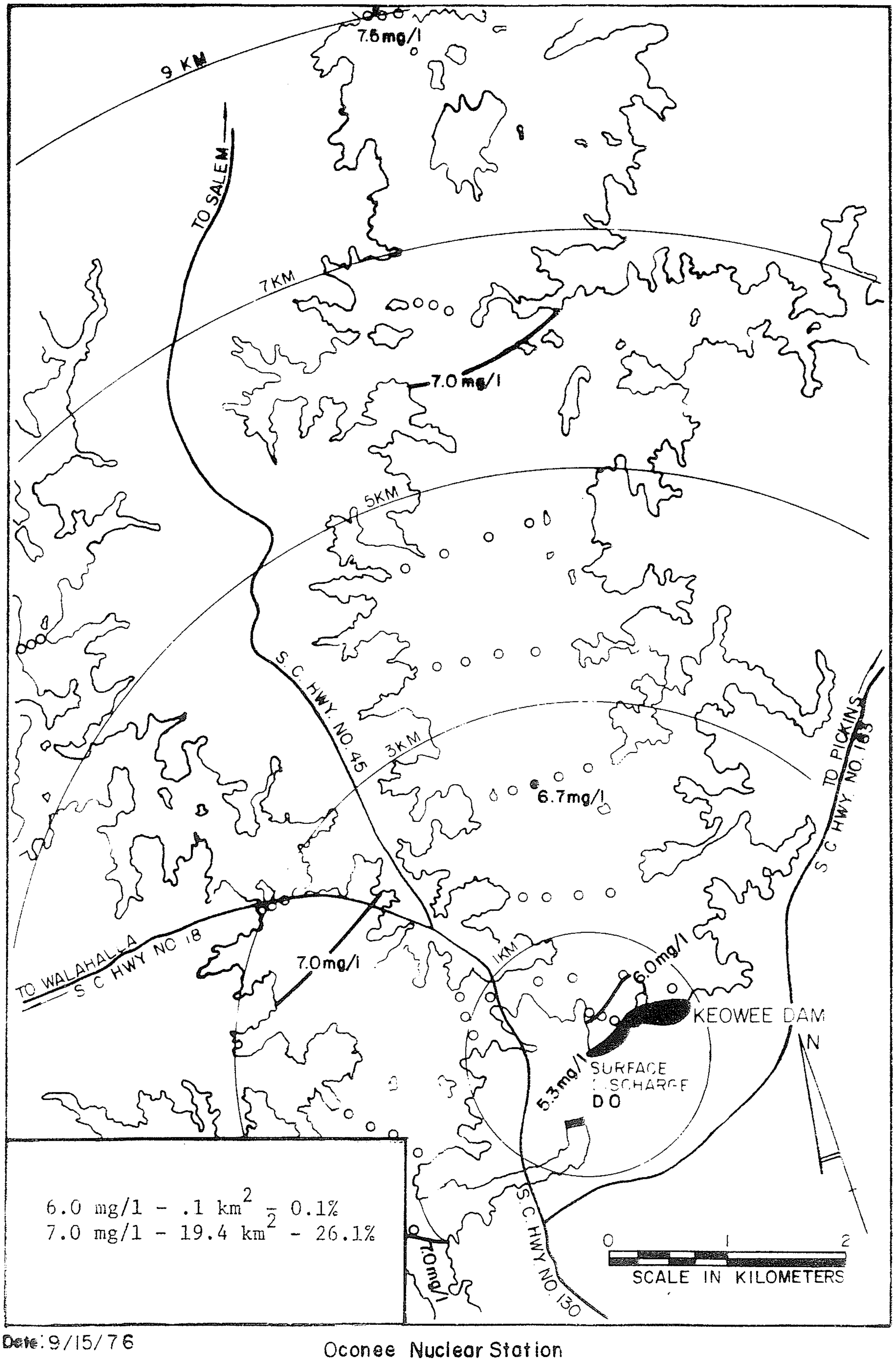
Figure: 3-7



Date:9/1/76

Oconee Nuclear Station
Plume Mapping Study
Surface D O(mg/l)

Figure:3-8



6.0 mg/1 - .1 km^2 = 0.1%
7.0 mg/1 - 19.4 km^2 - 26.1%

Date: 9/15/76

Oconee Nuclear Station
Plume Mapping Study
Surface D O (mg/l)

Figure: 3-9

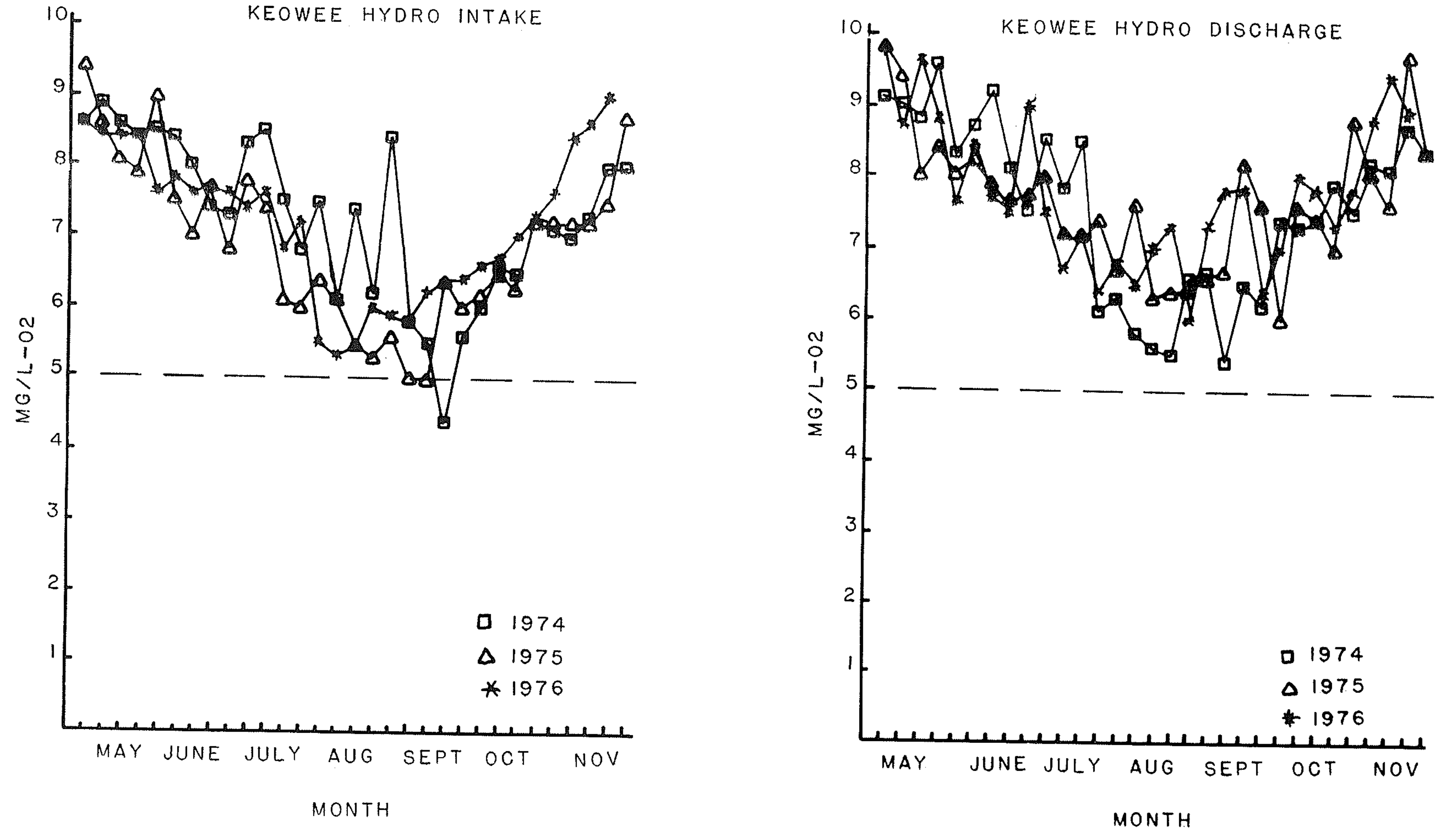


Figure 3-10. Weekly dissolved oxygen concentrations at Keowee Hydro Intake and Keowee Hydro Discharge from 1974 through 1976.

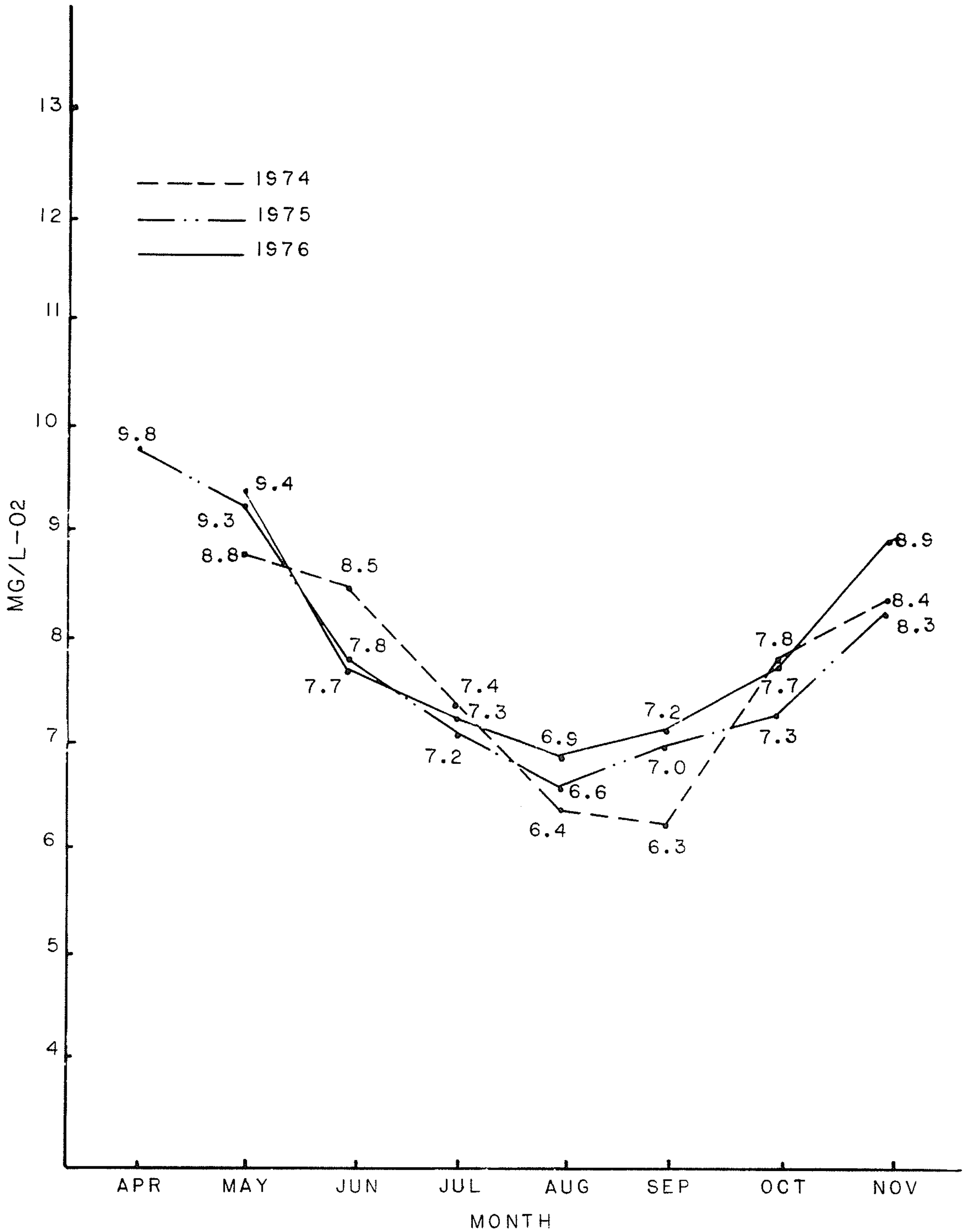


Figure 3-11. Monthly mean dissolved oxygen concentrations from weekly dissolved oxygen monitoring study at Location 605.0 on Lake Hartwell from April through November during the operational study period.

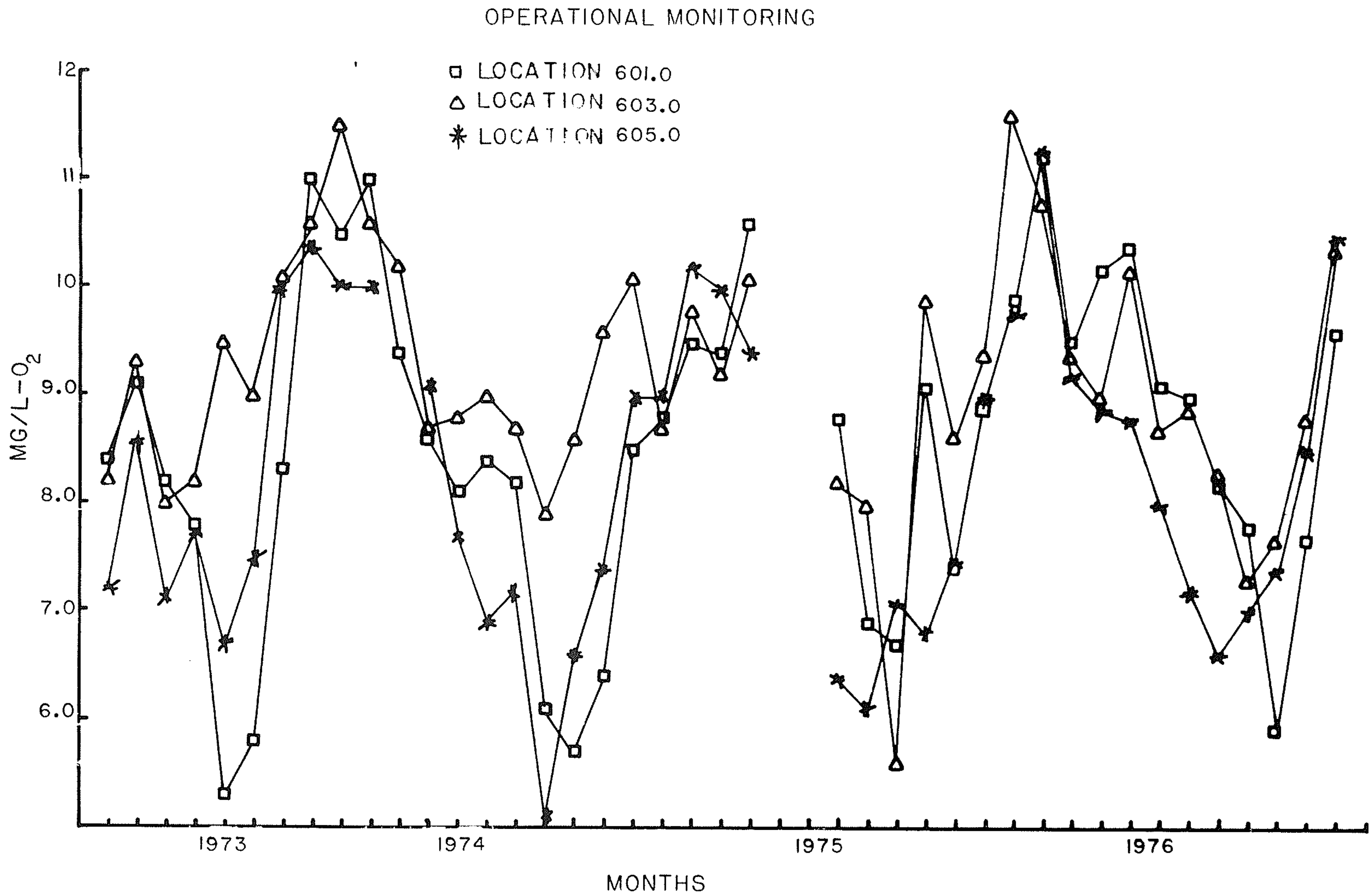


Figure 3-12. Monthly variations in surface dissolved oxygen concentrations at Locations 601.0, 603.0, and 605.0 on Lake Hartwell from June 1973 through December 1976.

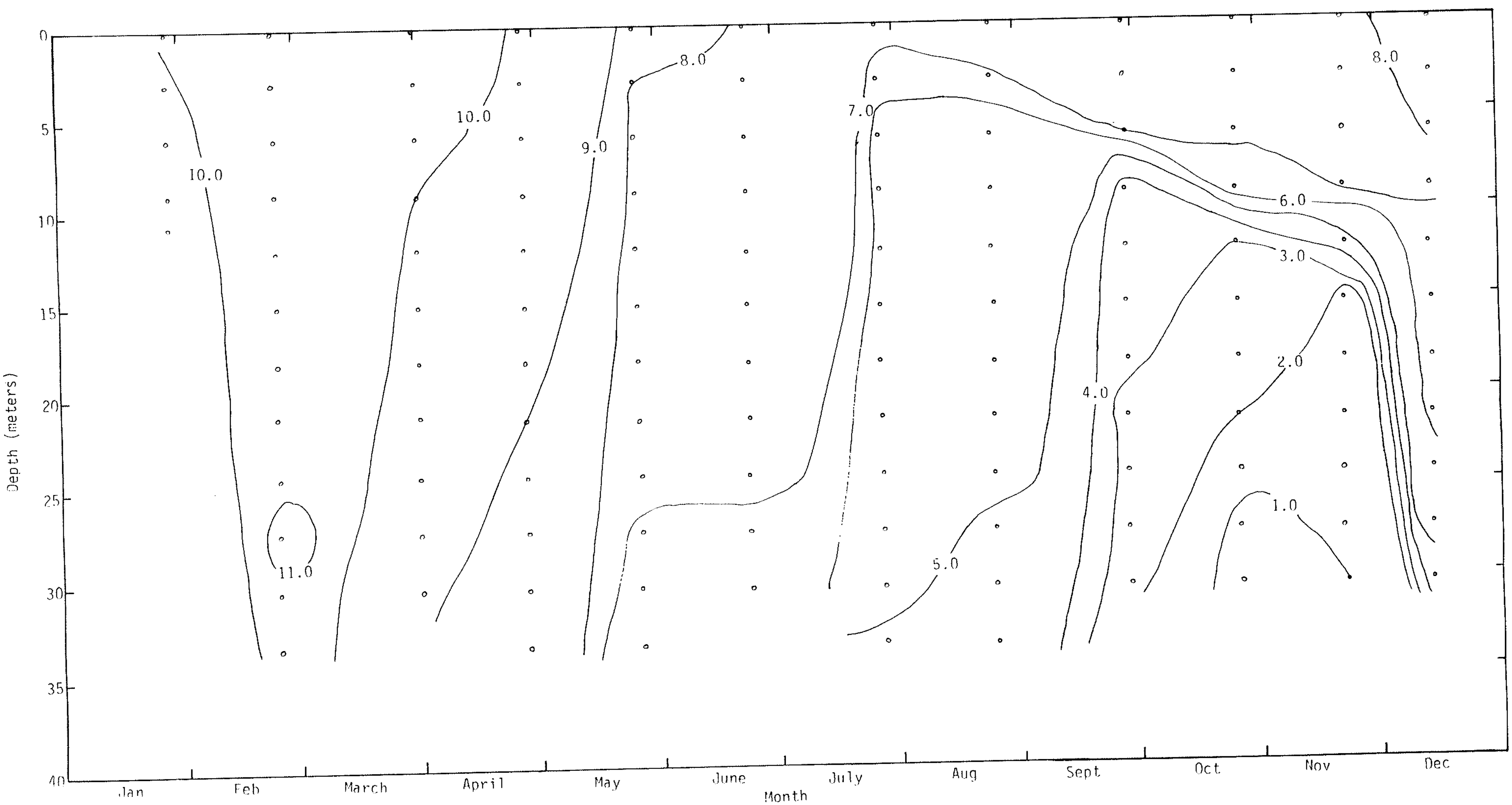


Figure 3-13 Dissolved Oxygen Isopleths (mg/l) for Location 501.0 on Lake Keowee for 1971

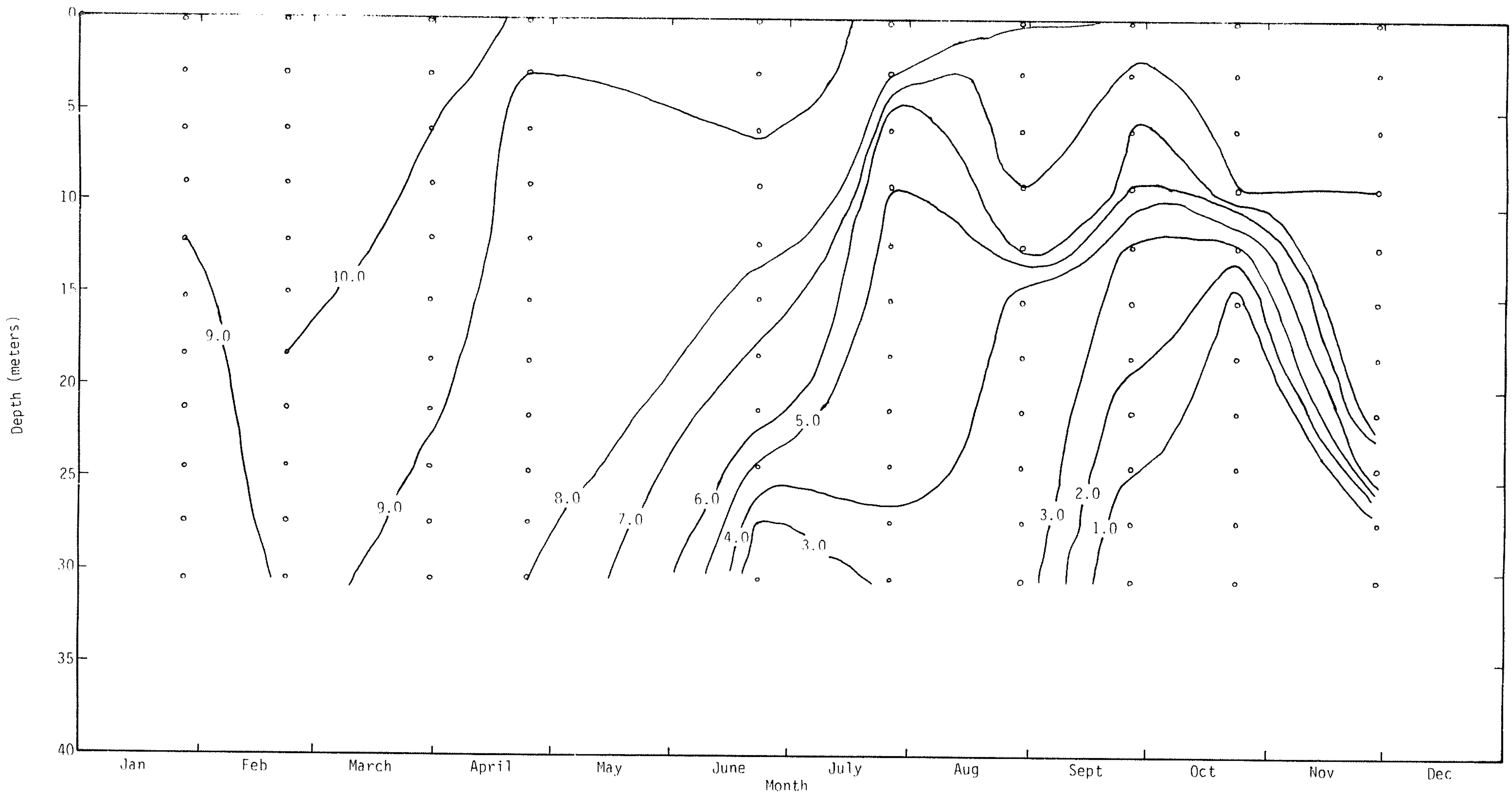


Figure 3-14 Dissolved Oxygen Isopleths (mg/l) for Location 501.0 on Lake Keowee for 1972

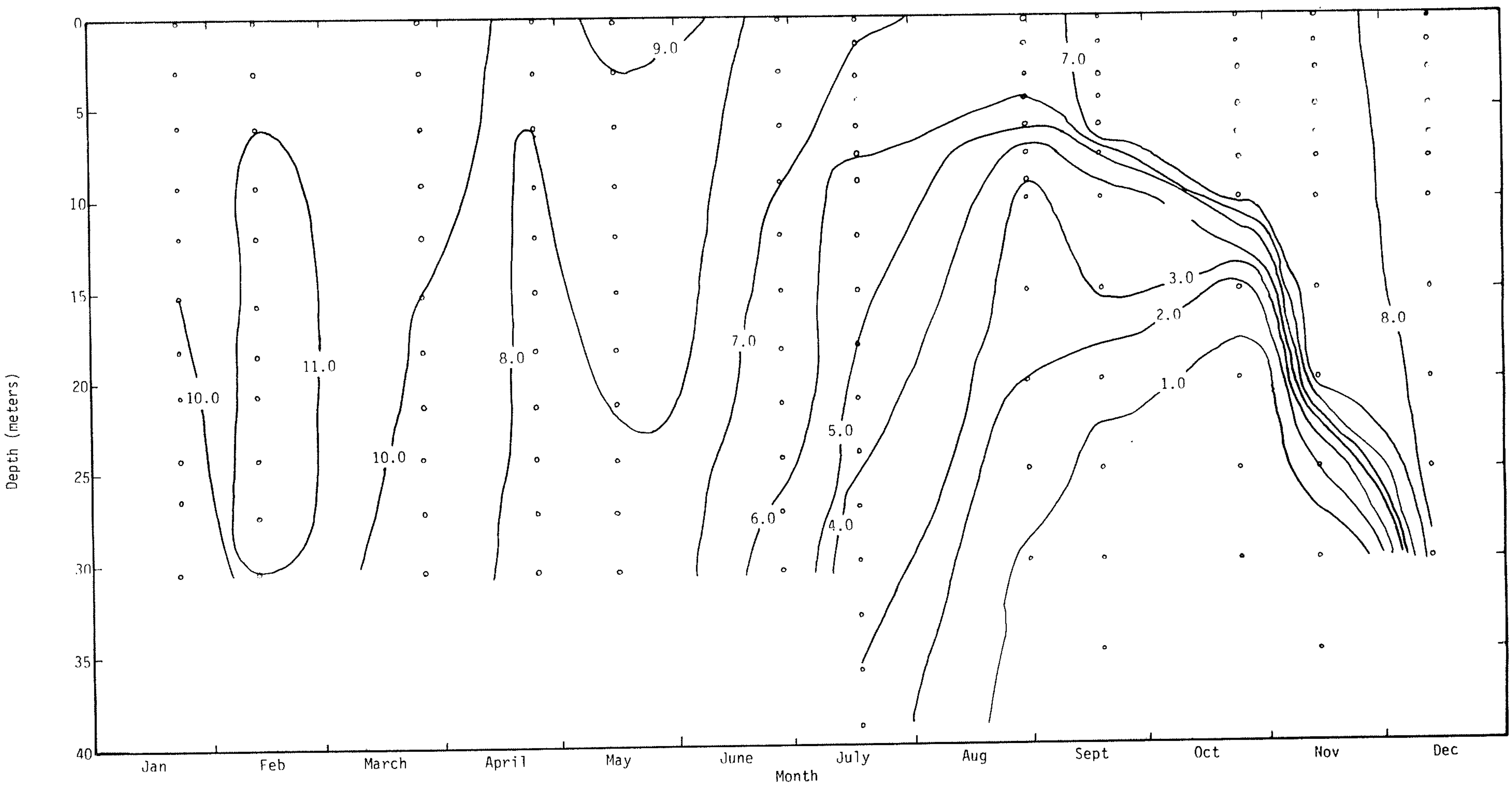


Figure 3-15 Dissolved Oxygen Isopleths (mg/l) for Location 501.0 on Lake Keowee for 1973

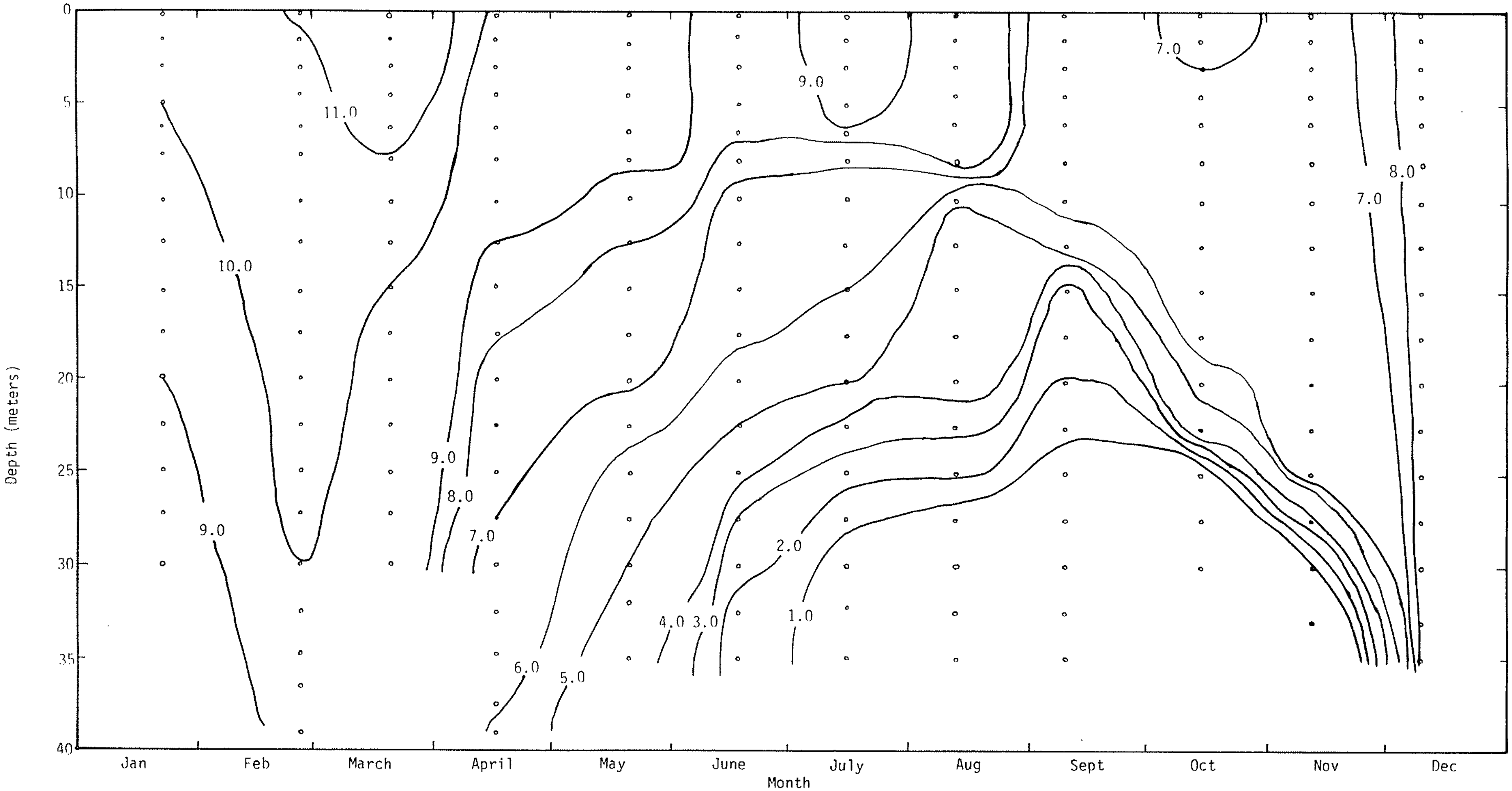


Figure 3-16 Dissolved Oxygen Isopleths (mg/1) for Location 501.0 on Lake Keowee for 1974

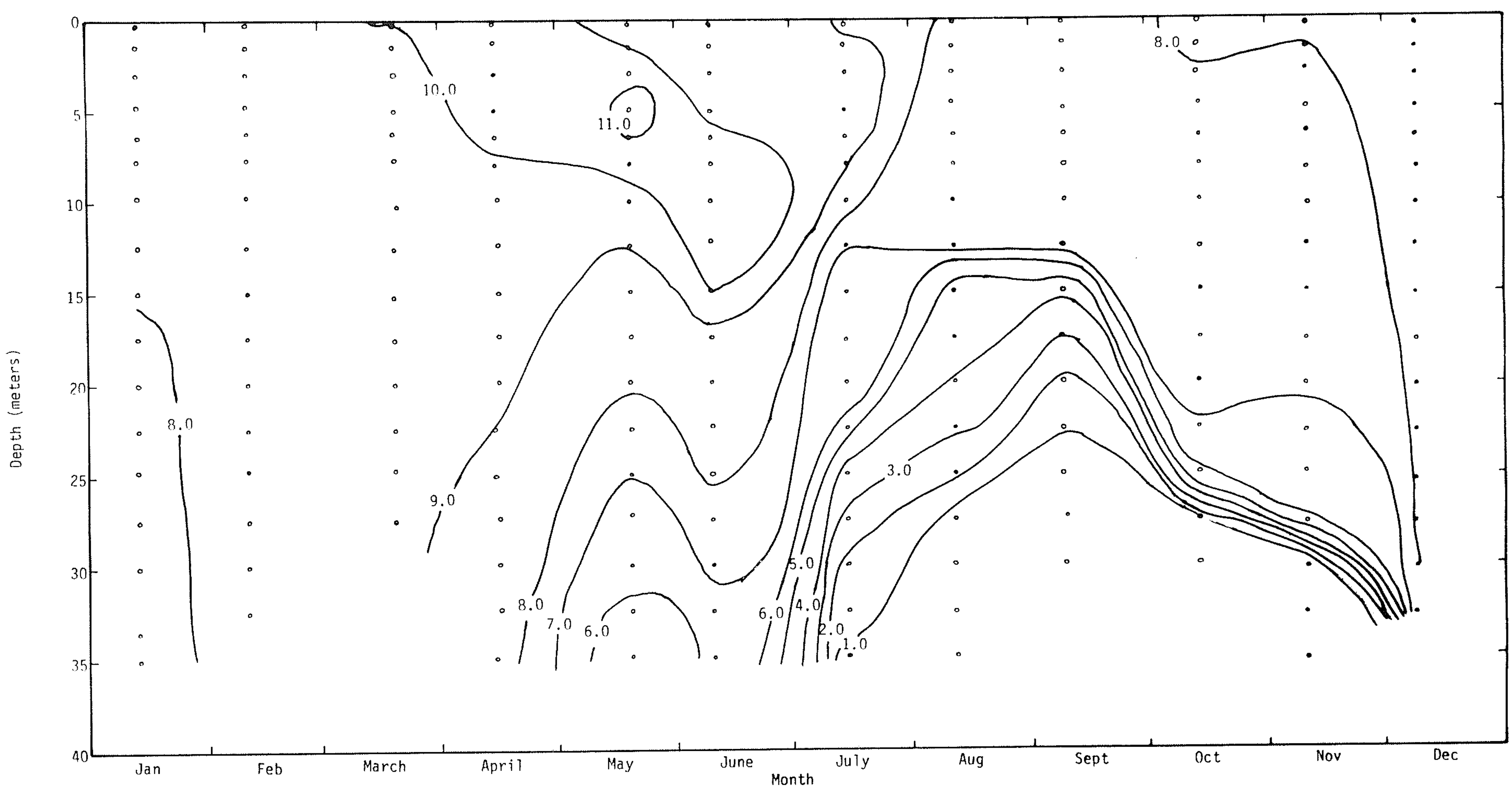


Figure 3-17 Dissolved Oxygen Isopleths (mg/l) for Location 501.0 on Lake Keowee for 1975

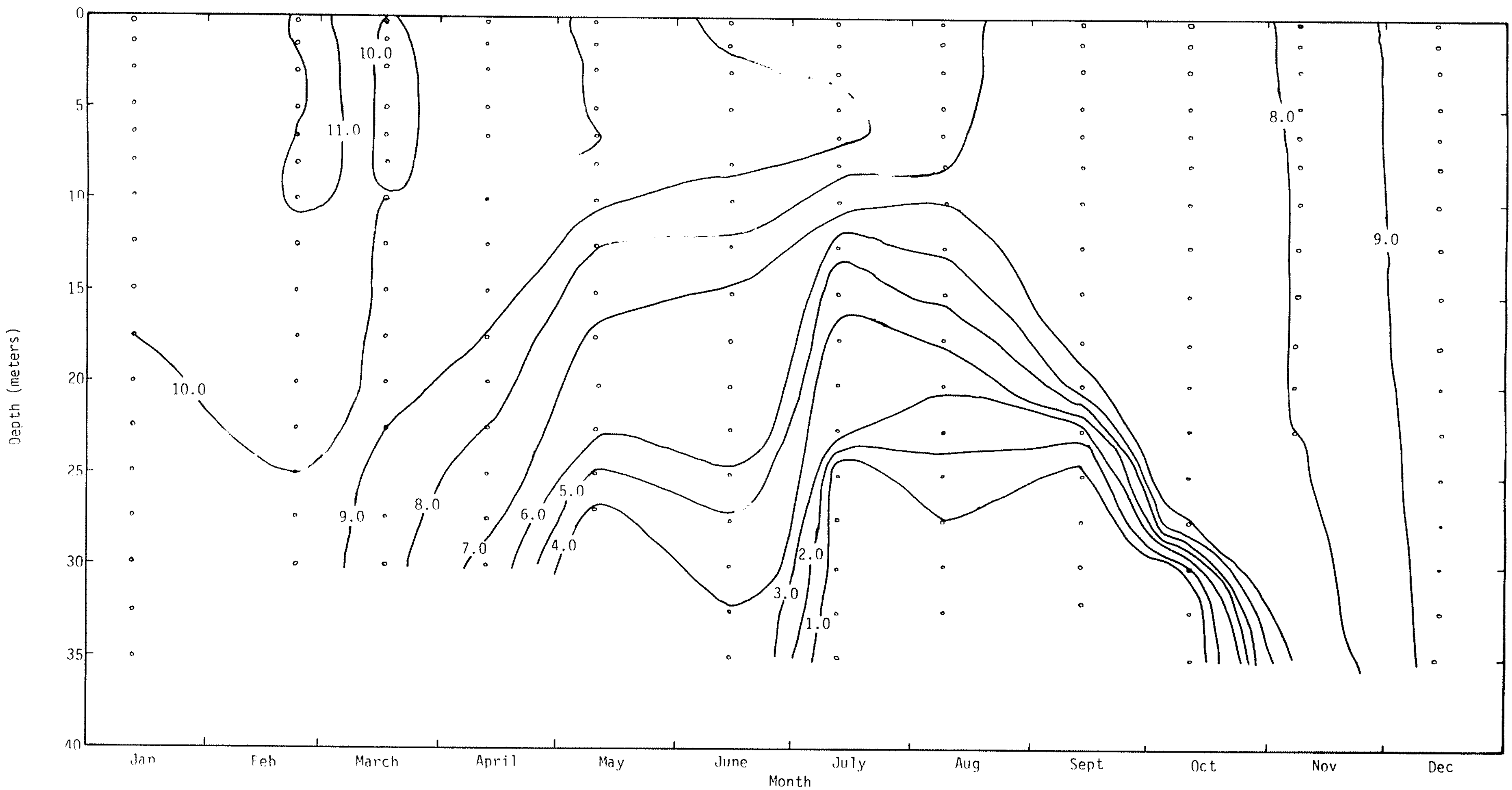


Figure 3-18 Dissolved Oxygen Isopleths (mg/l) for Location 501.0 on Lake Keowee for 1976

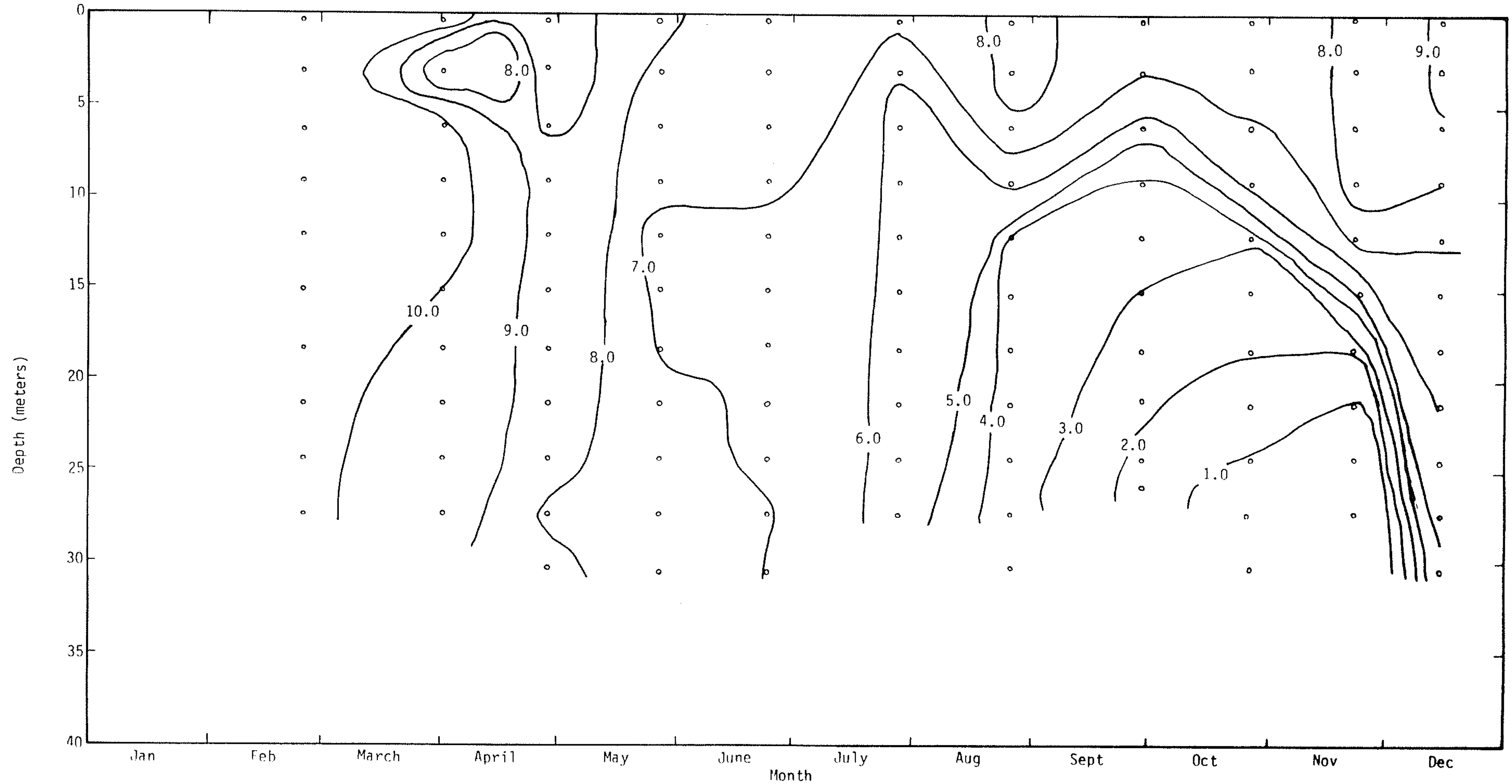


Figure 3-19 Dissolved Oxygen Isopleths (mg/l) for Location 502.0 on Lake Keowee for 1971

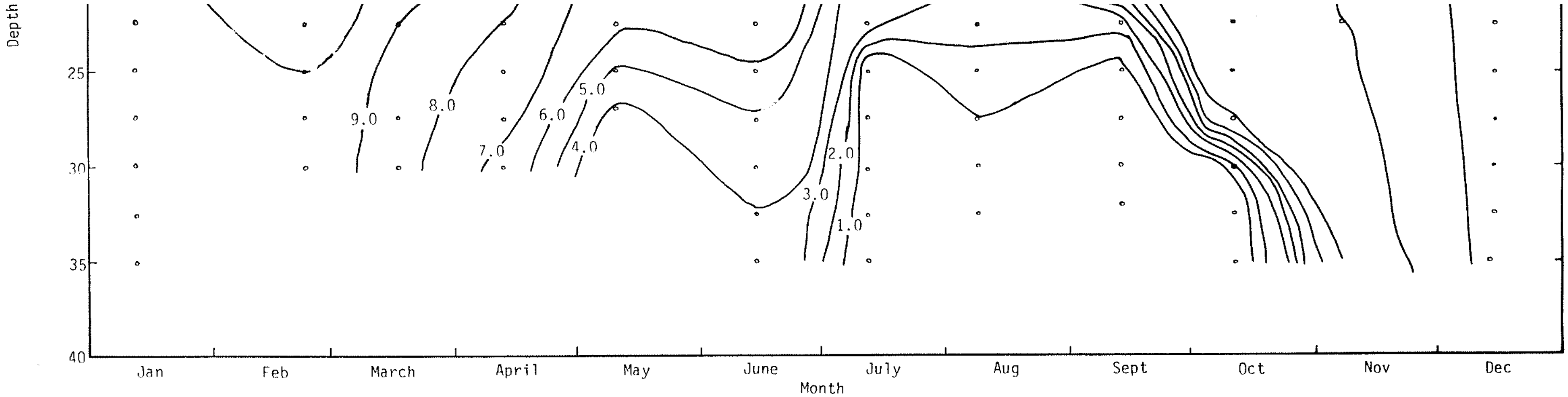


Figure 3-18 Dissolved Oxygen Isopleths (mg/l) for Location 501.0 on Lake Keowee for 1976

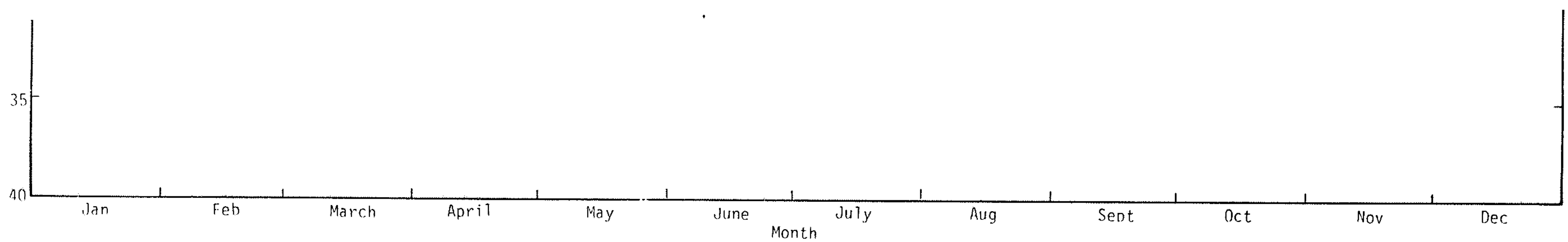


Figure 3-20 Dissolved Oxygen Isopleths (mg/l) for Location 502.0 on Lake Keowee for 1972

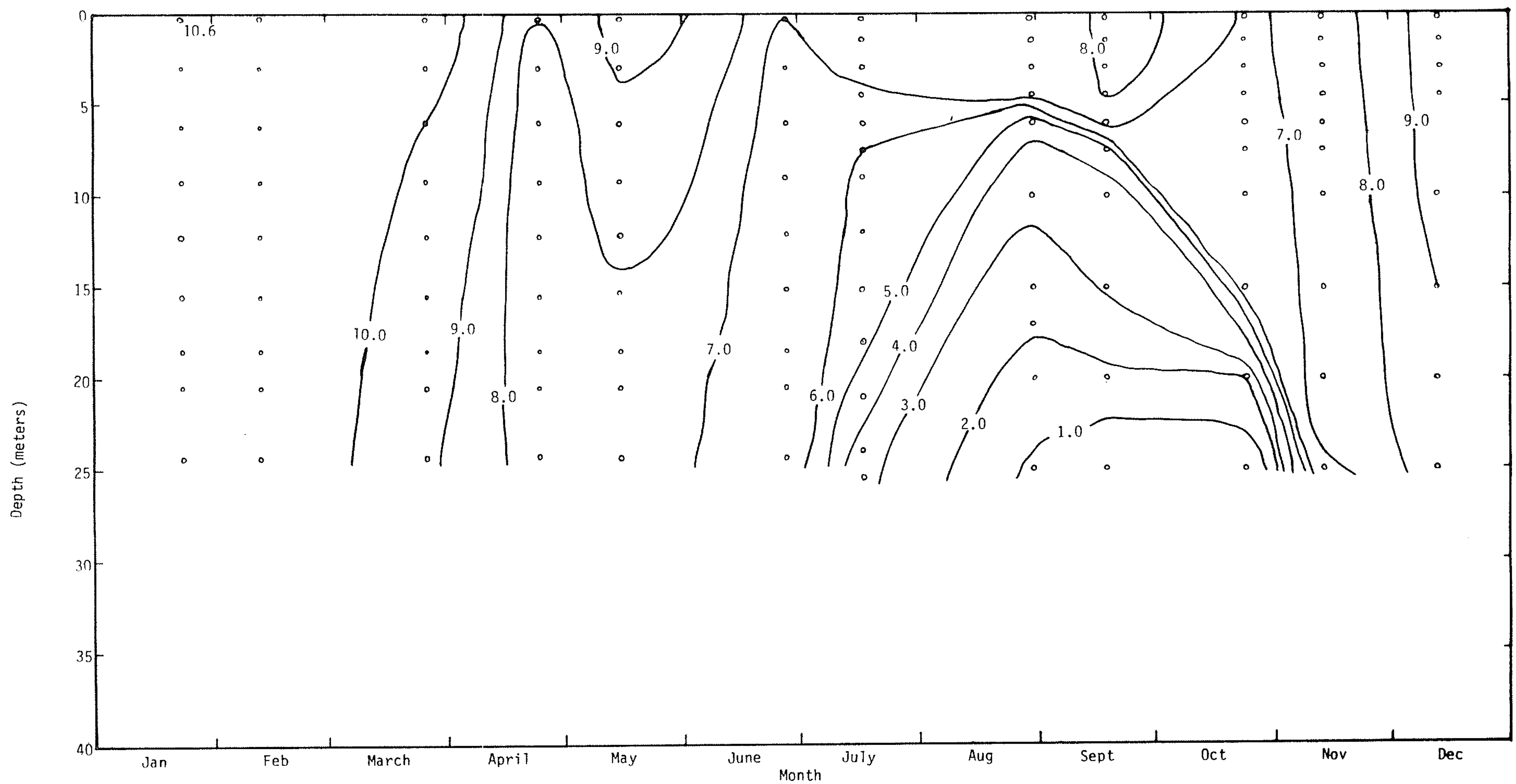


Figure 3-21 Dissolved Oxygen Isopleths (mg/l) for Location 502.0 on Lake Keowee for 1973

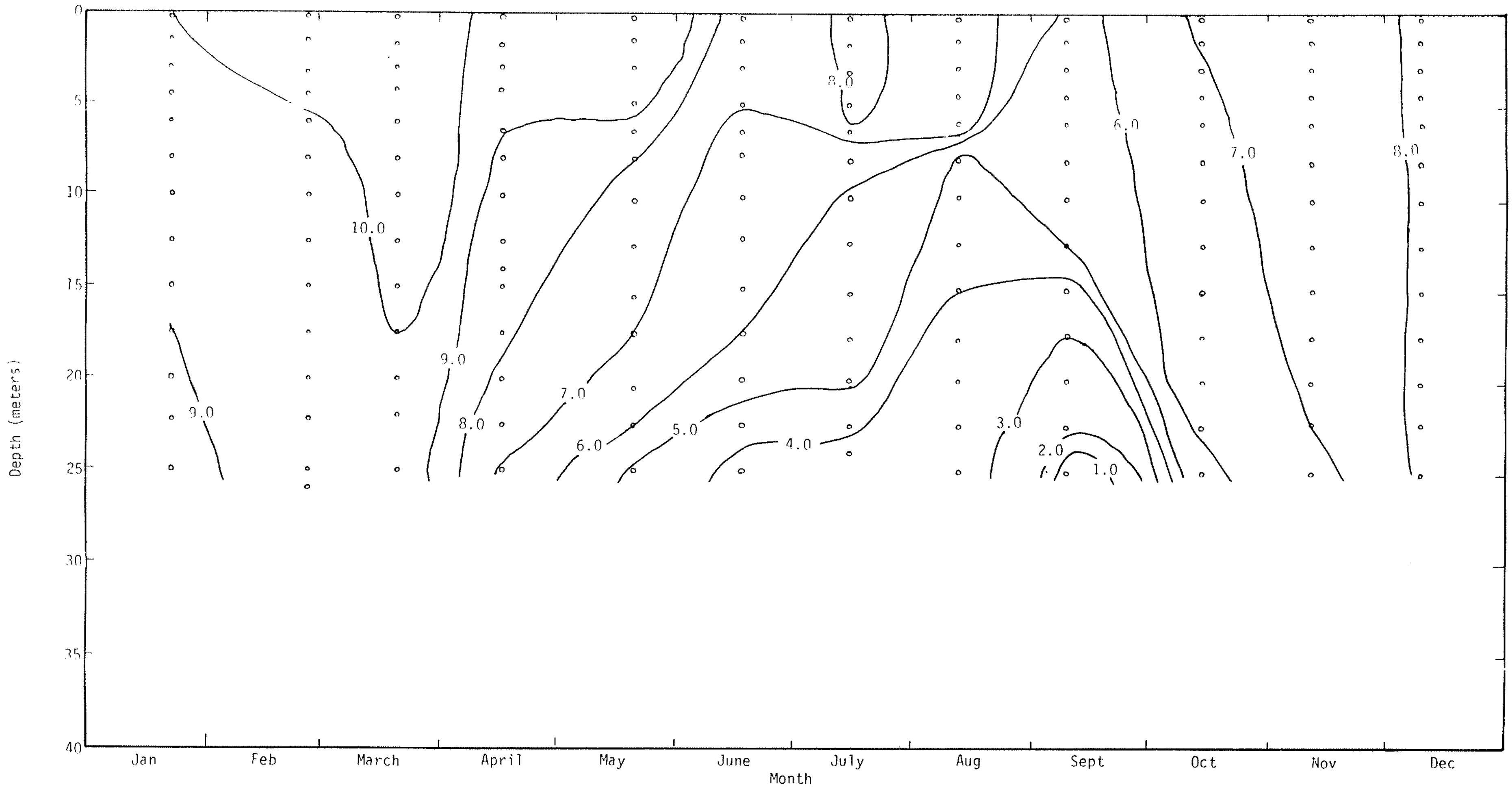


Figure 3-22 Dissolved Oxygen Isopleths (mg/l) for Location 502.0 on Lake Keowee for 1974

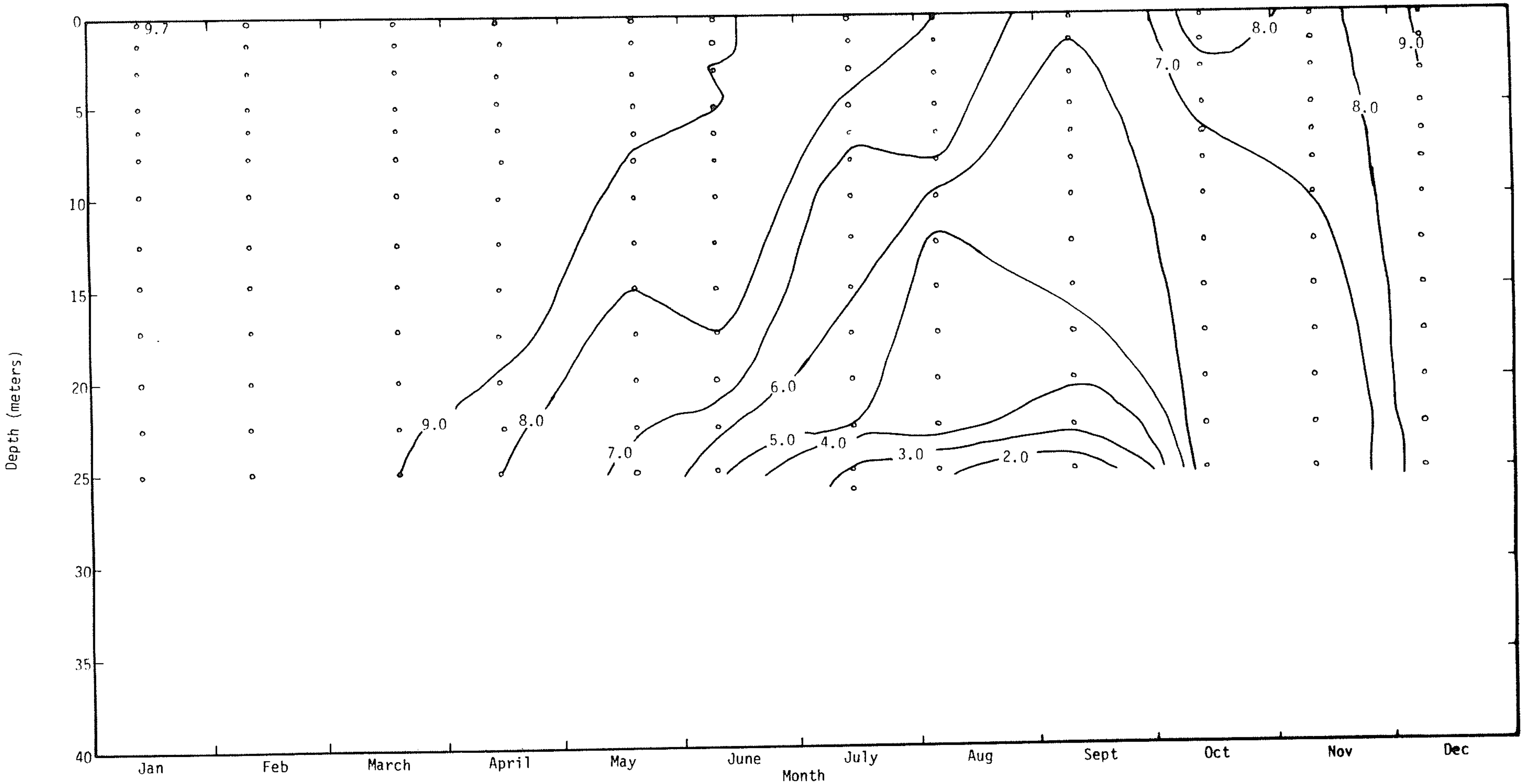


Figure 3-23 Dissolved Oxygen Isopleths (mg/1) for Location 502.0 on Lake Keowee for 1975

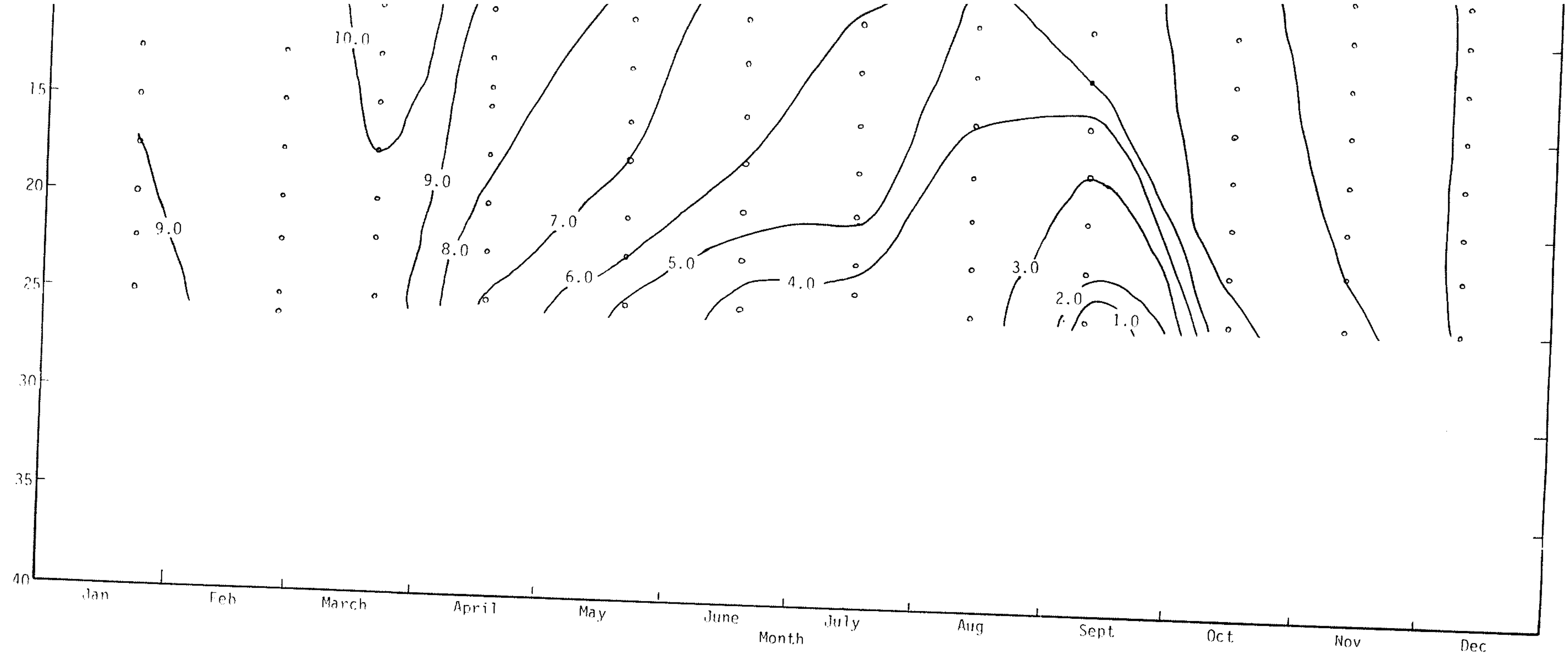


Figure 3-22 Dissolved Oxygen Isopleths (mg/l) for Location 502.0 on Lake Keowee for 1974

Figure 3-24 Dissolved Oxygen Isopleths (mg/l) for Location 502.0 on Lake Keowee for 1976

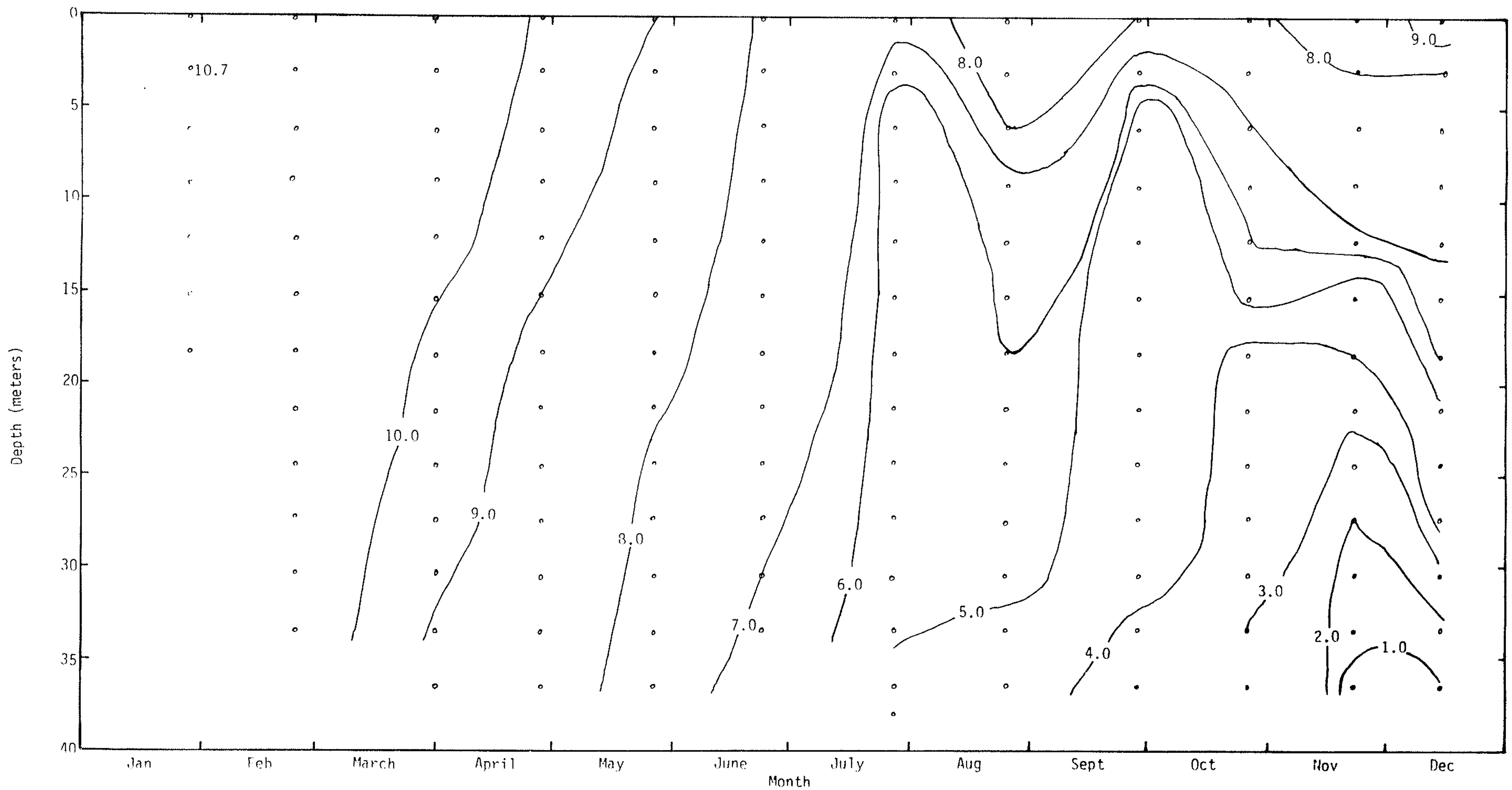


Figure 3-25 Dissolved Oxygen Isopleths (mg/l) for Location 504.0 on Lake Keowee for 1971

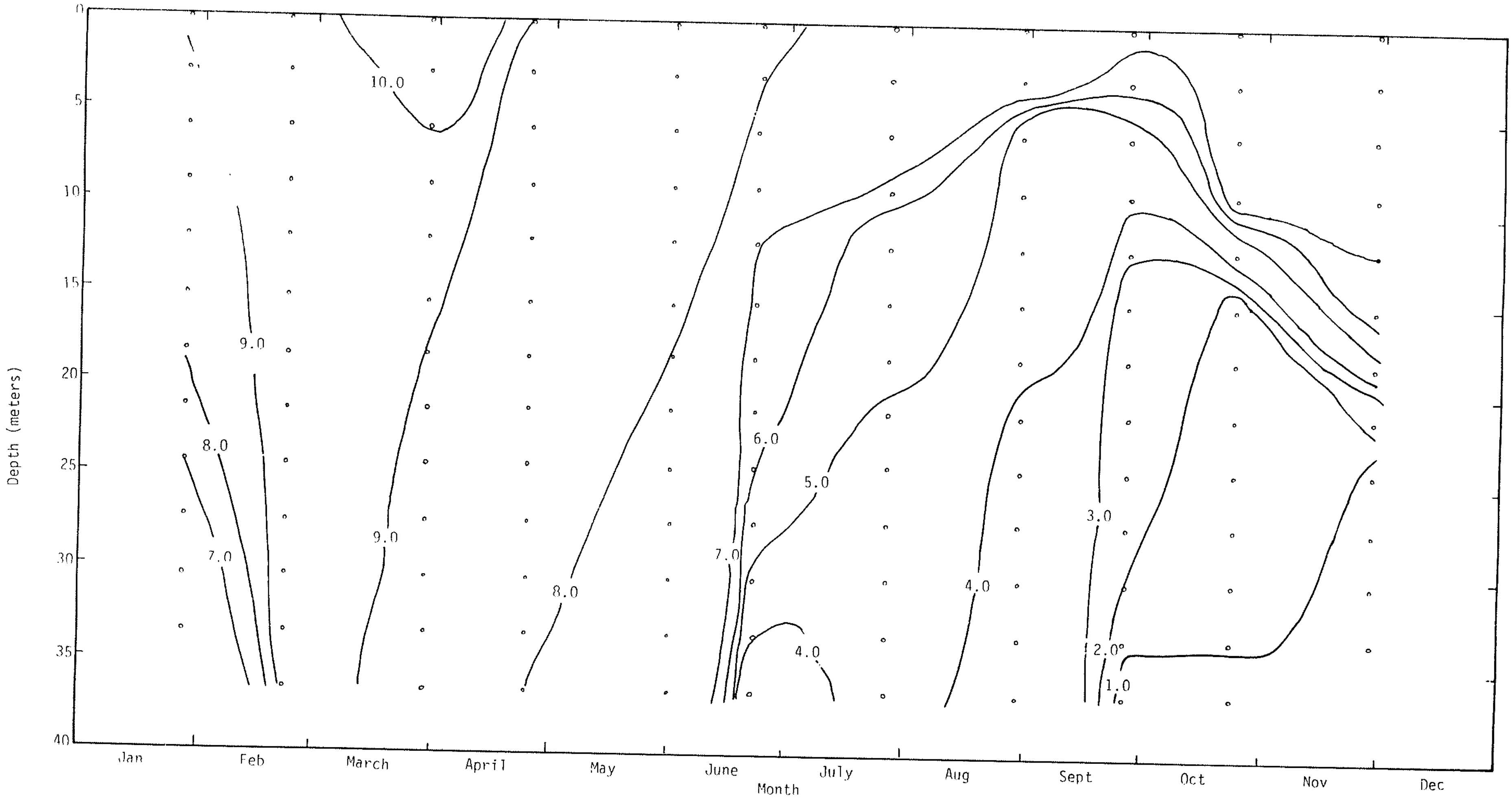


Figure 3-26 Dissolved Oxygen Isopleths (mg/l) for Location 504.0 on Lake Keowee for 1972

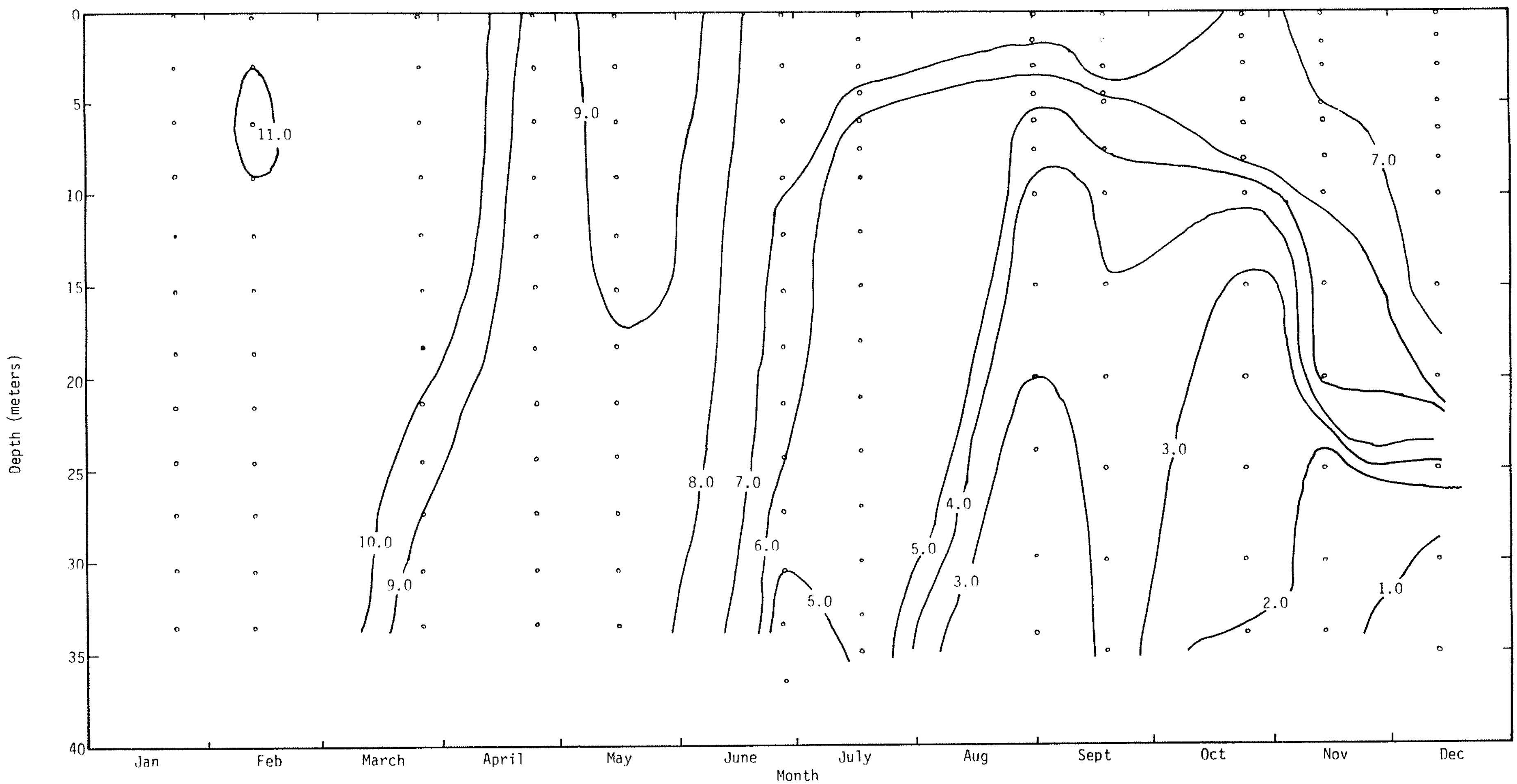


Figure 3-27 Dissolved Oxygen Isopleths (mg/l) for Location 504.0 on Lake Keowee for 1973

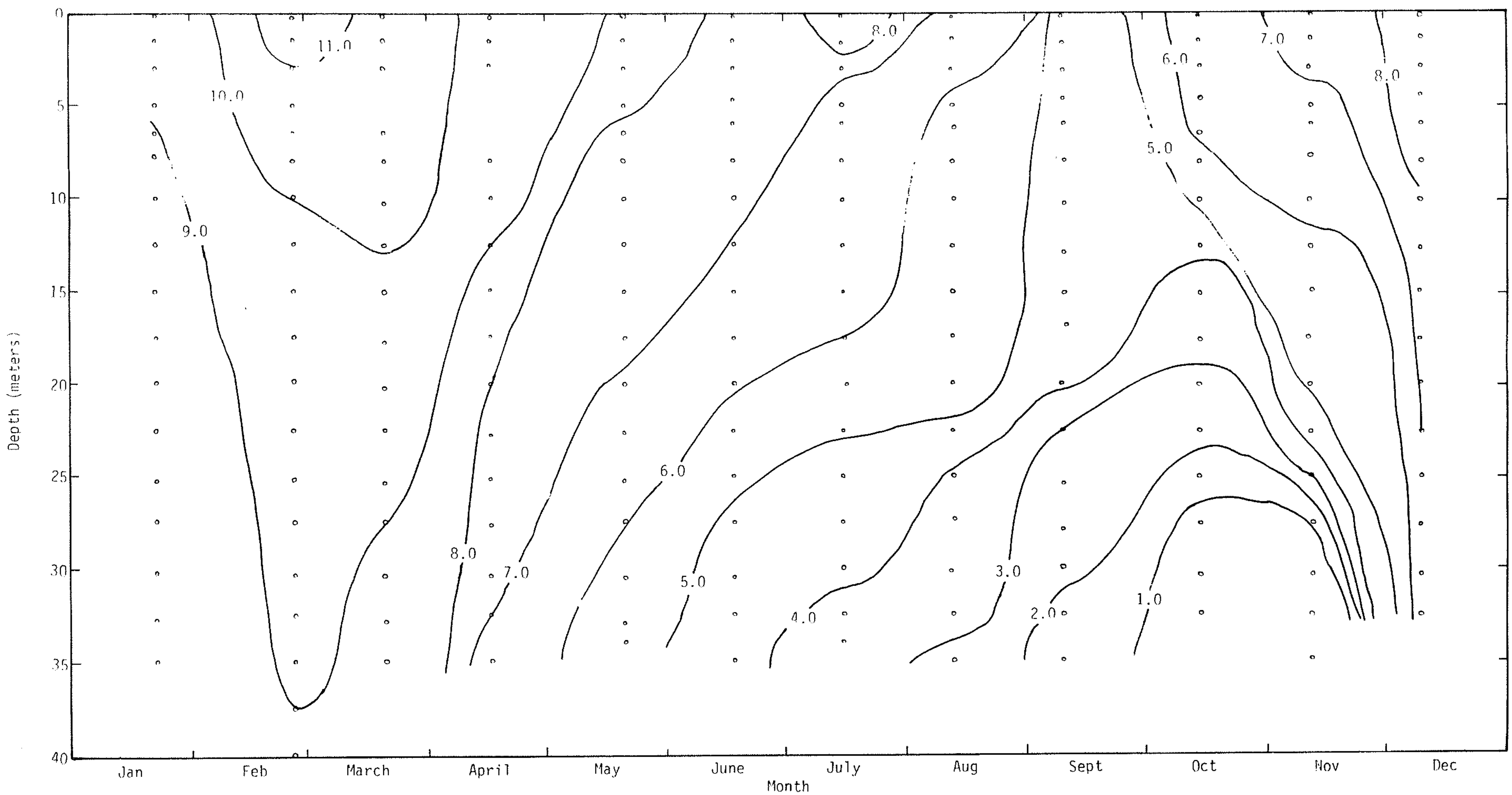


Figure 3-28 Dissolved Oxygen Isopleths (mg/l) for Location 504.0 on Lake Keowee for 1974

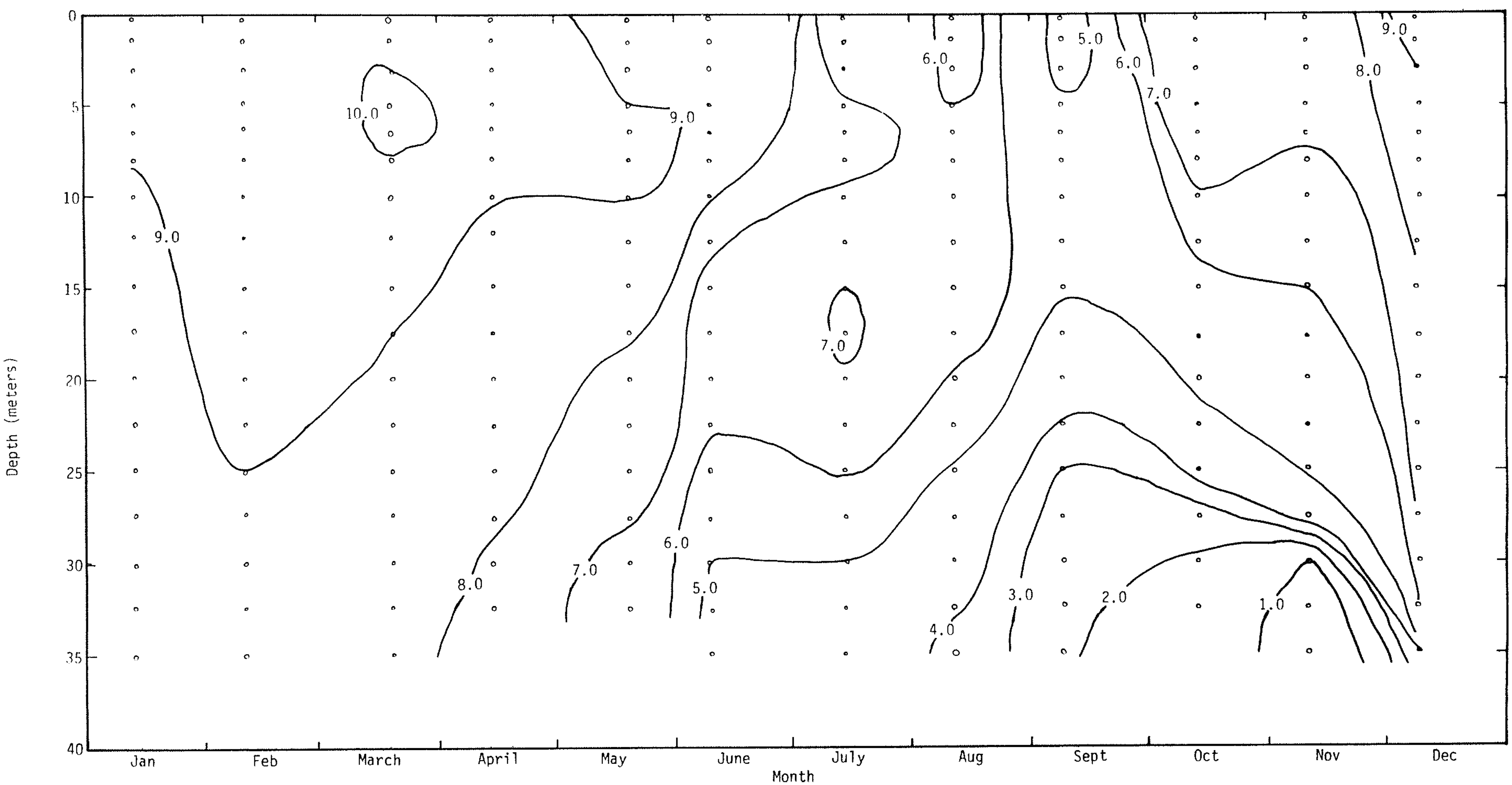


Figure 3-29 Dissolved Oxygen Isopleths (mg/l) for Location 504.0 on Lake Keowee for 1975

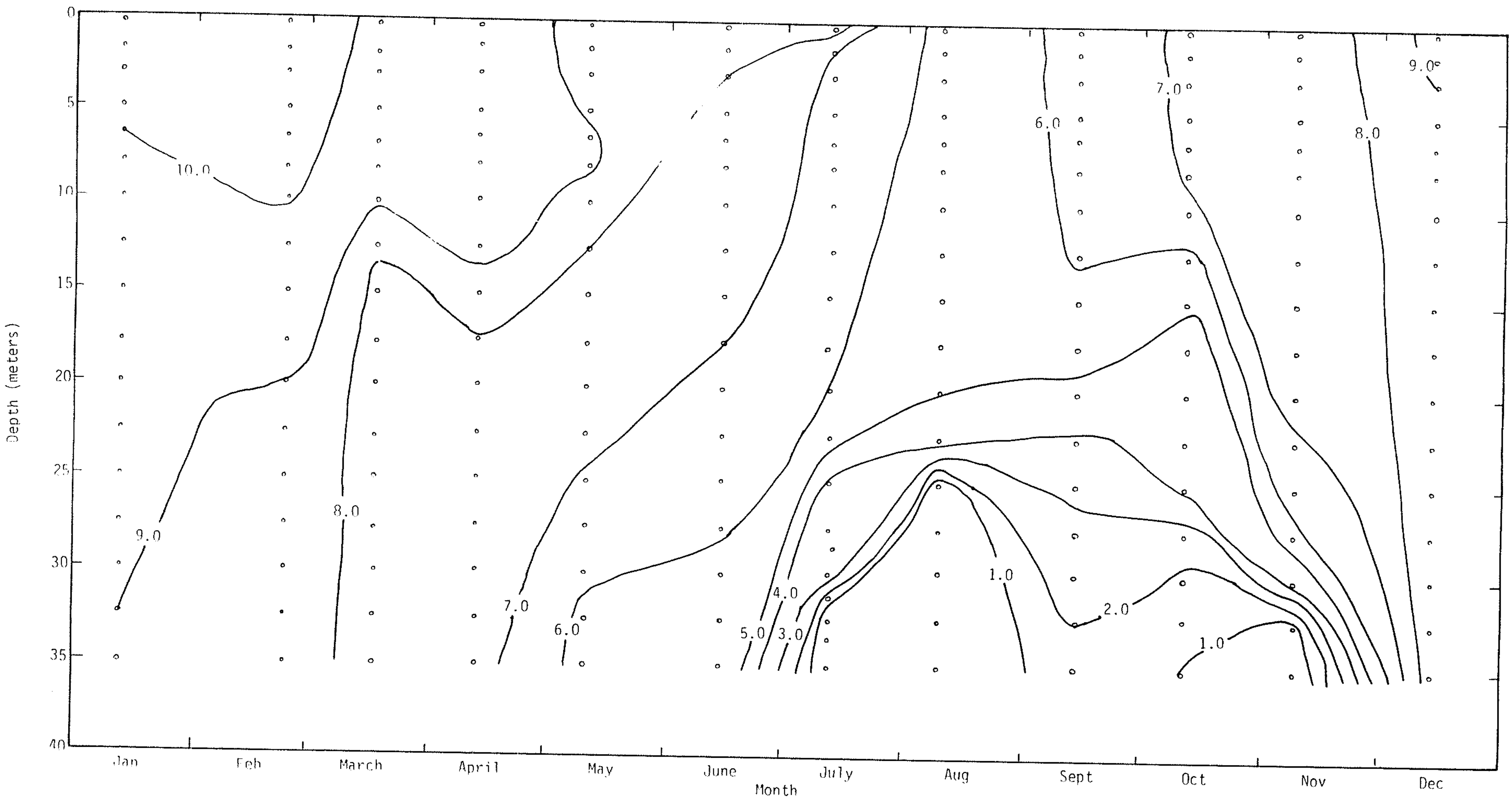


Figure 3-30 Dissolved Oxygen Isopleths (mg/l) for Location 504.0 on Lake Keowee for 1976

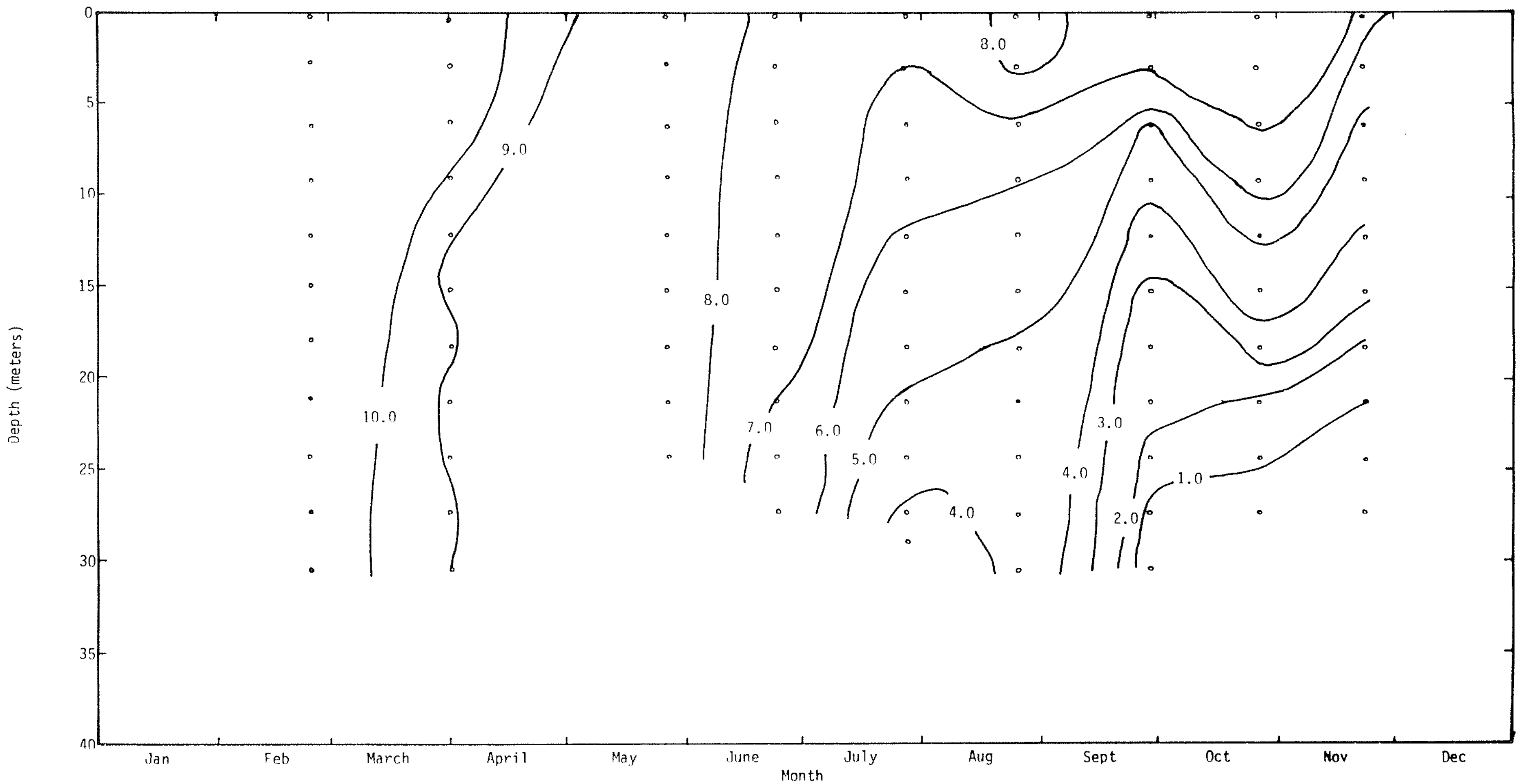


Figure 3-31 Dissolved Oxygen Isopleths (mg/1) for Location 506.0 on Lake Keowee for 1971

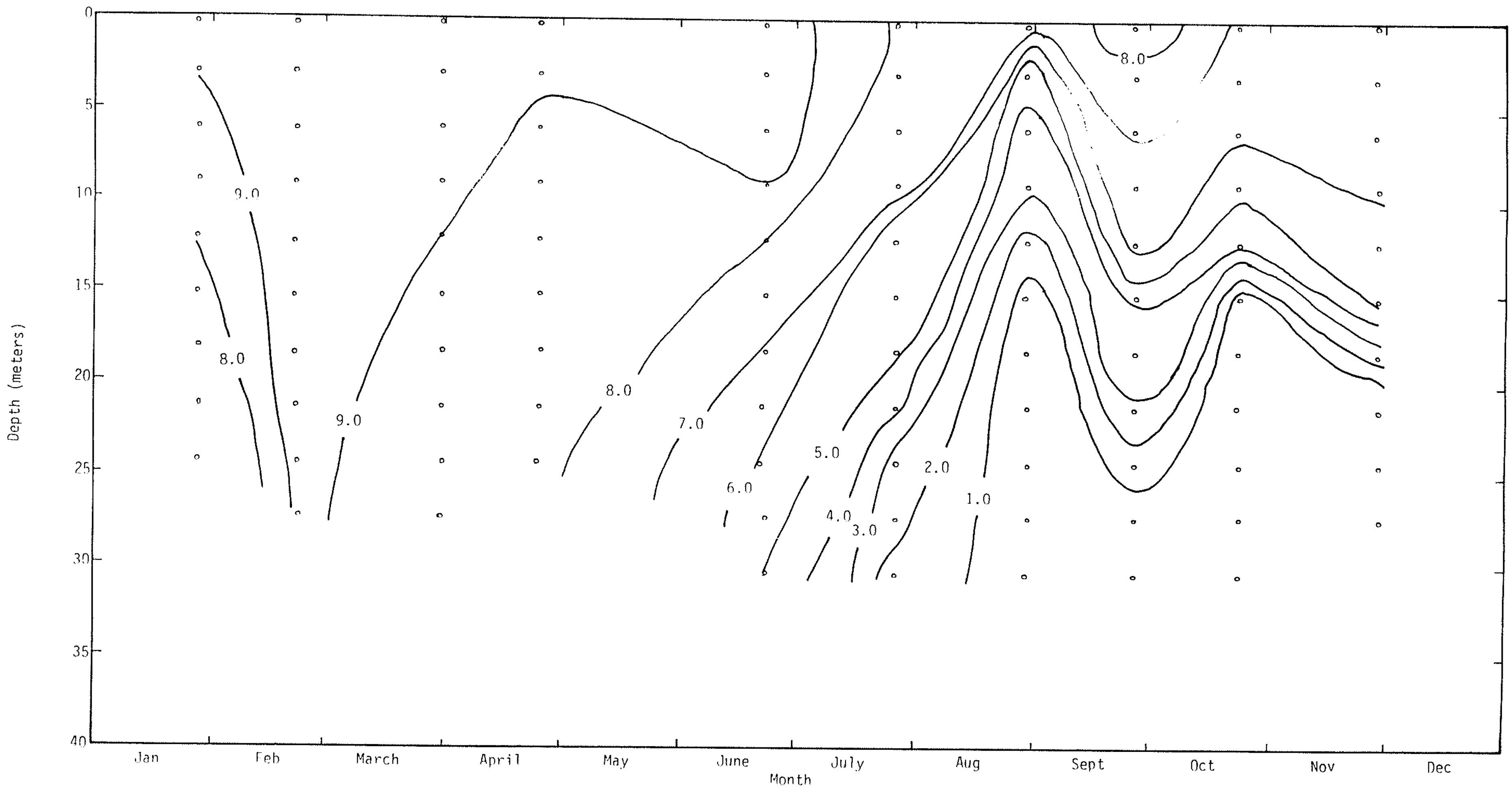


Figure 3-32 Dissolved Oxygen Isopleths (mg/l) for Location 506.0 on Lake Keowee for 1972

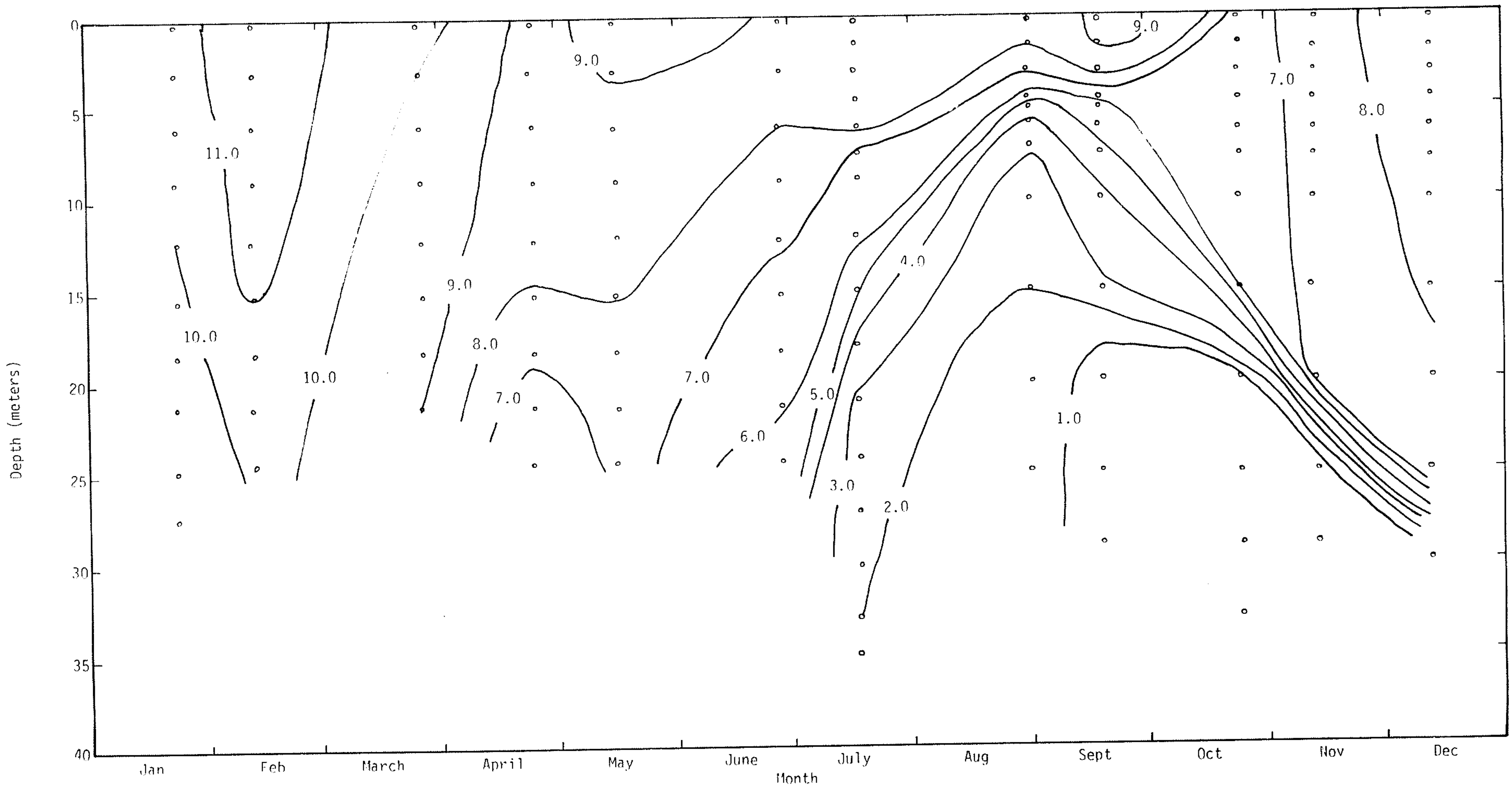


Figure 3-33 Dissolved Oxygen Isopleths (mg/l) for Location 506.0 on Lake Keowee for 1973

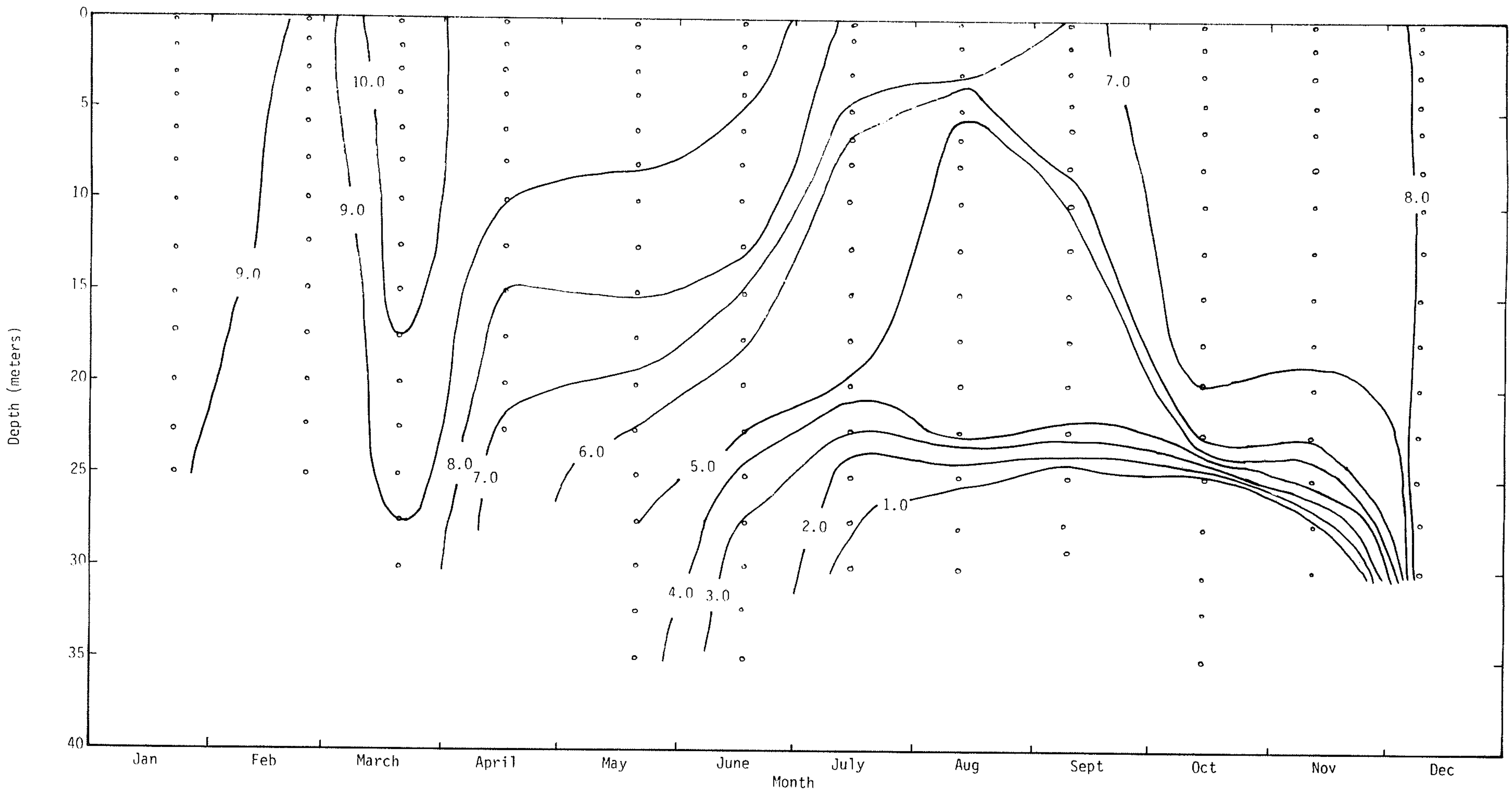


Figure 3-34 Dissolved Oxygen Isopleths (mg/1) for Location 506.0 on Lake Keowee for 1974

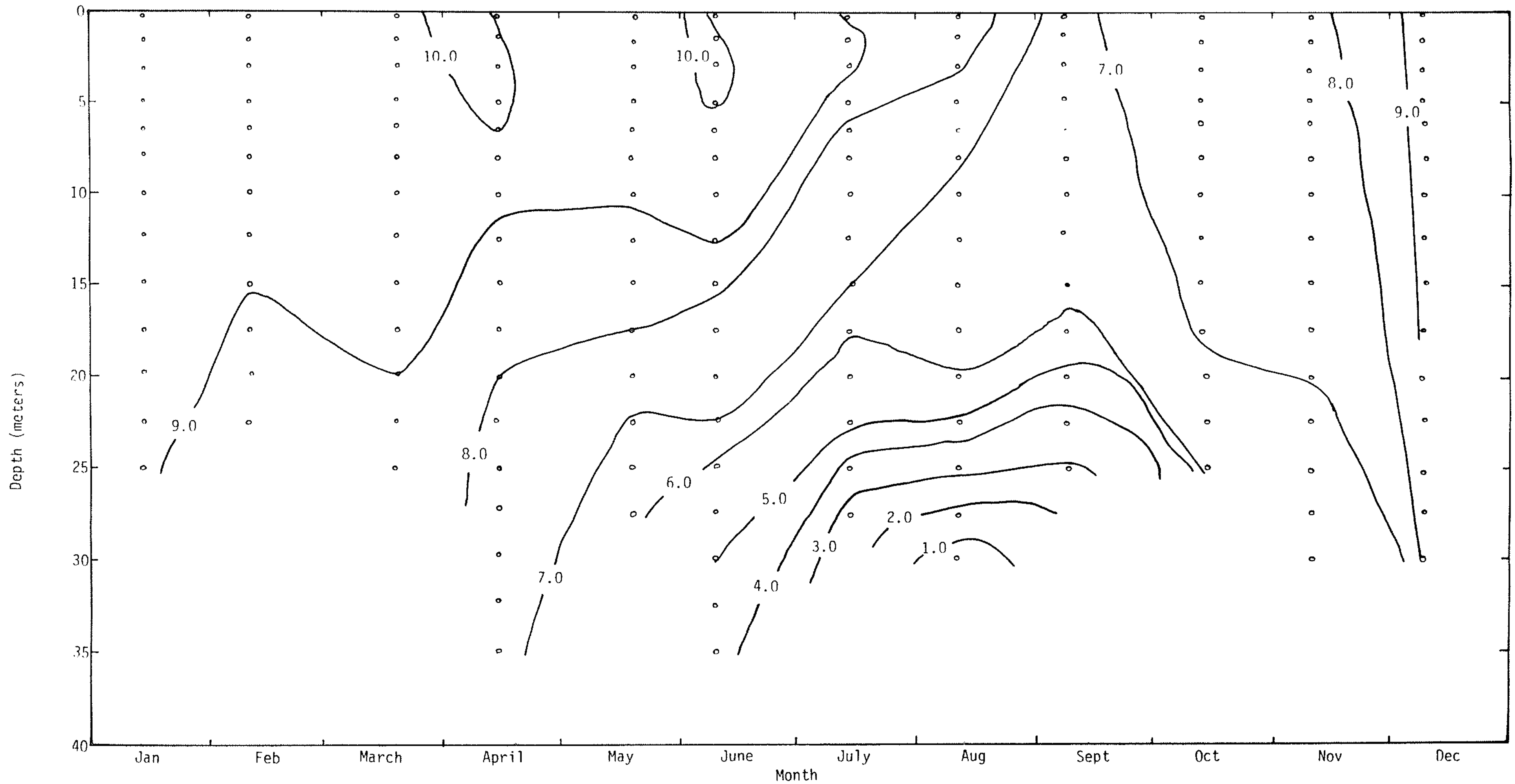


Figure 3-35 Dissolved Oxygen Isopleths (mg/l) for Location 506.0 on Lake Keowee for 1975

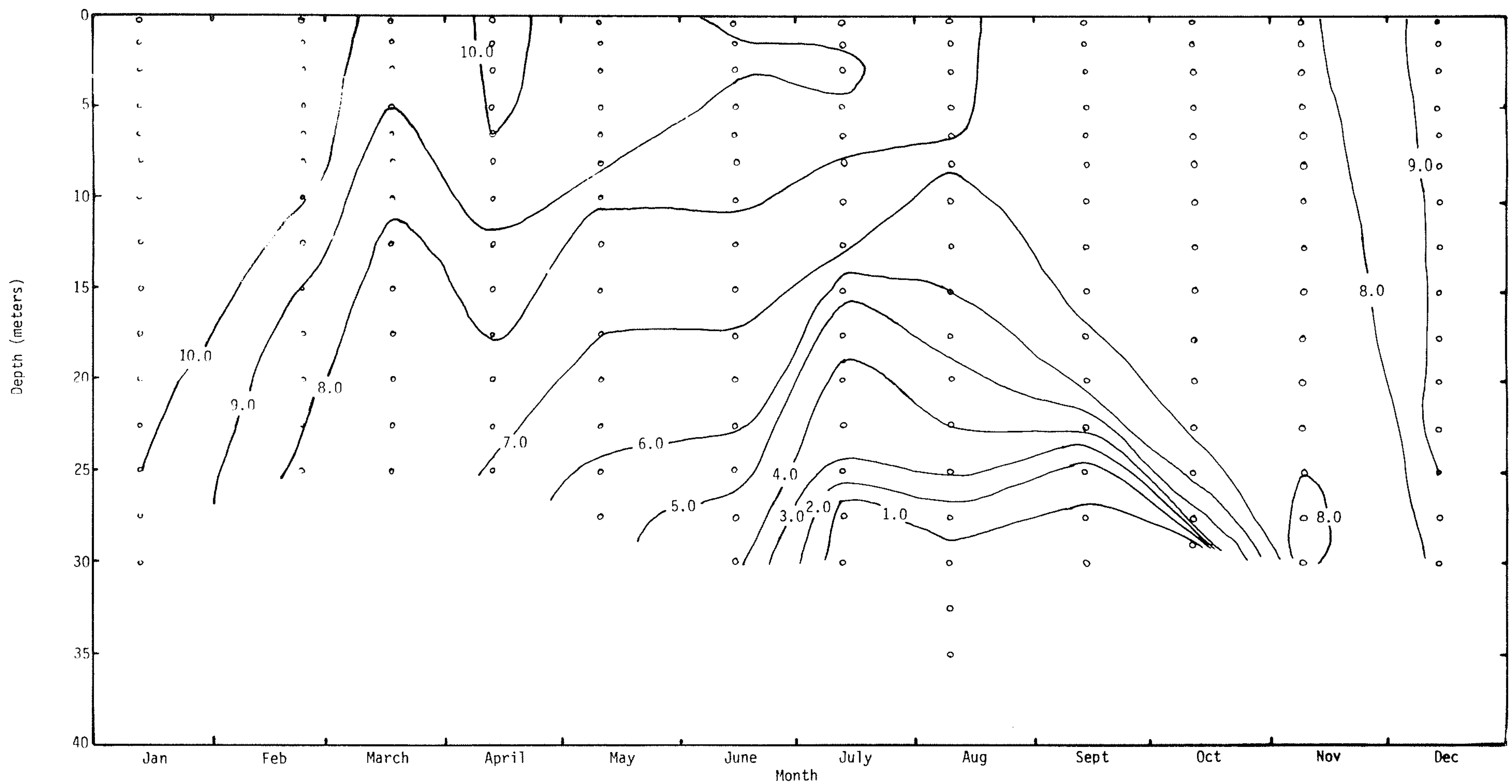


Figure 3-36 Dissolved Oxygen Isopleths (mg/l) for Location 506.0 on Lake Keowee for 1976

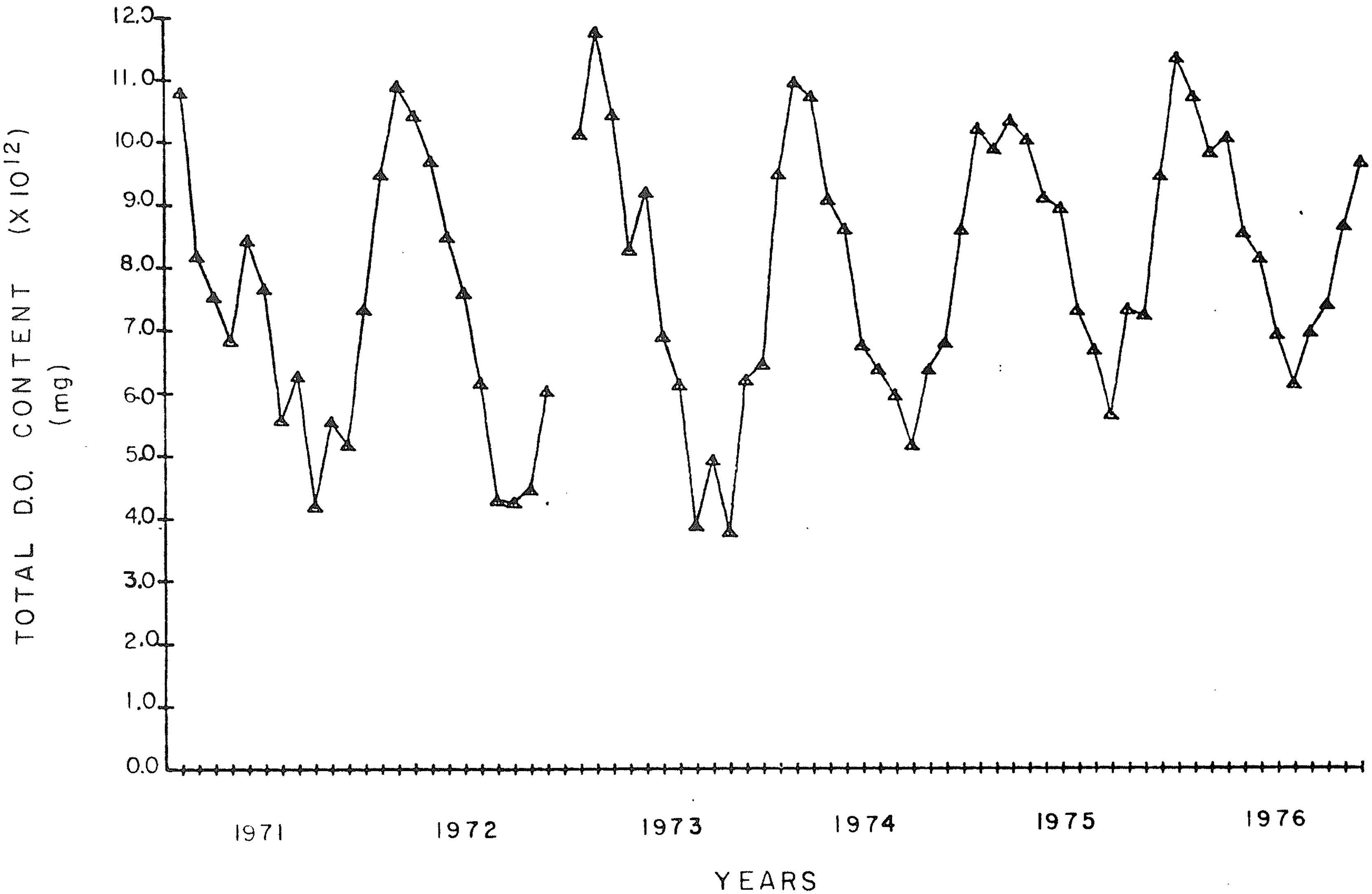


Figure 3-37. Total dissolved oxygen content for Lake Keowee from January 1971 through December 1976.

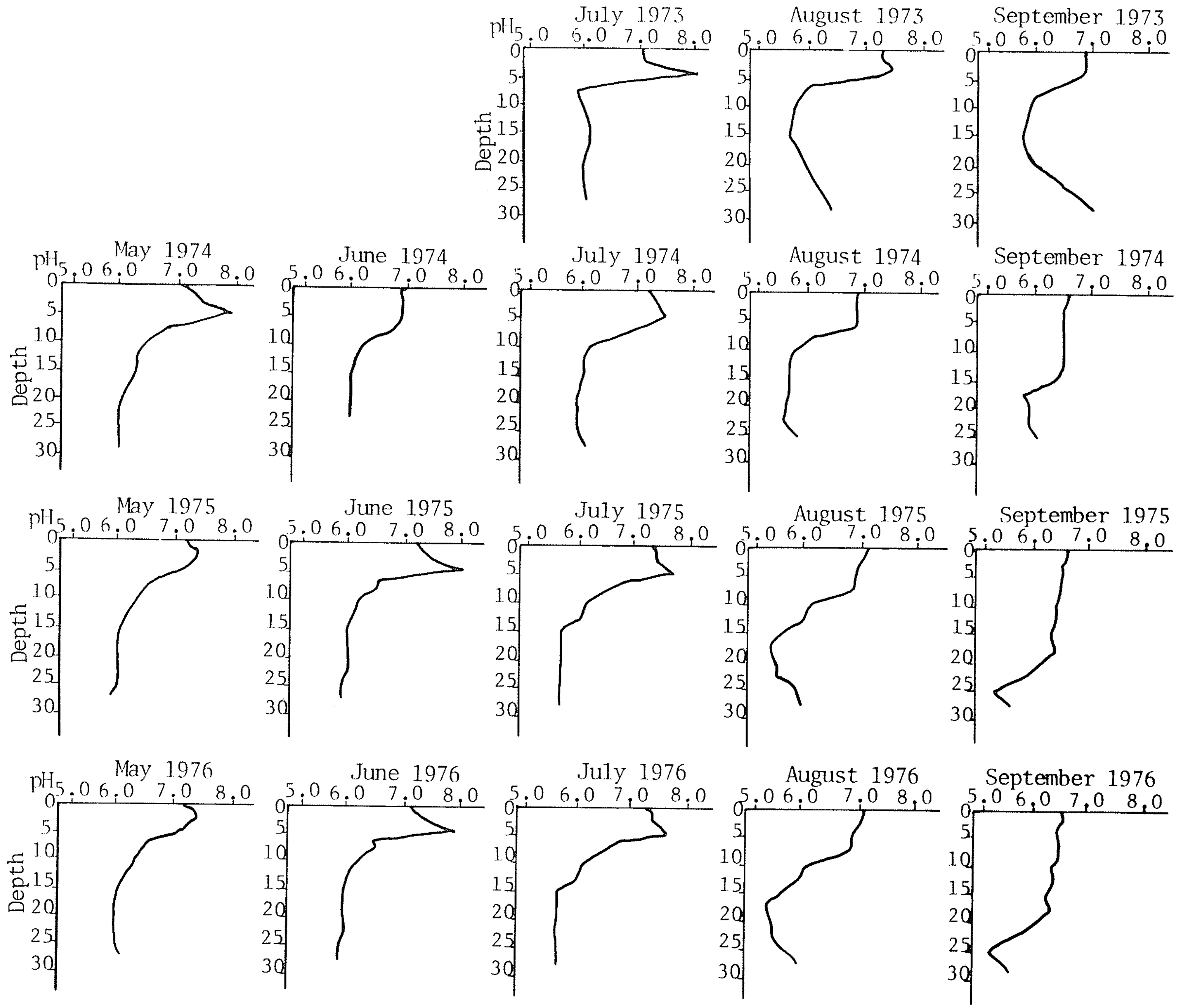


Figure 3-38. Vertical distribution of pH at Location 500.0 from May through September during operational study period (July 1973 through December 1976).

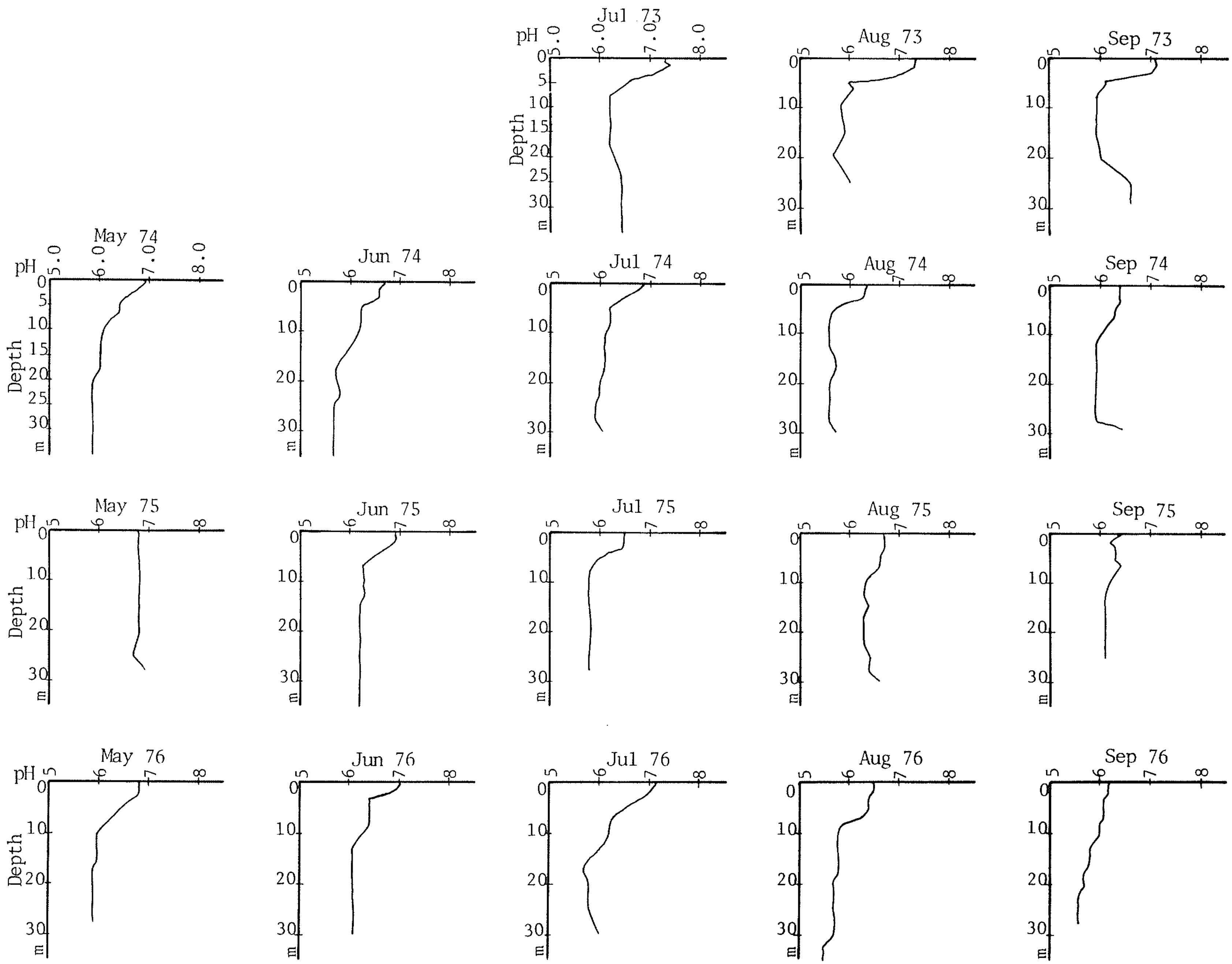


Figure 3-39. Vertical distribution of pH at Location 506.0 from May through September during operational study period (July 1973 through December 1976).

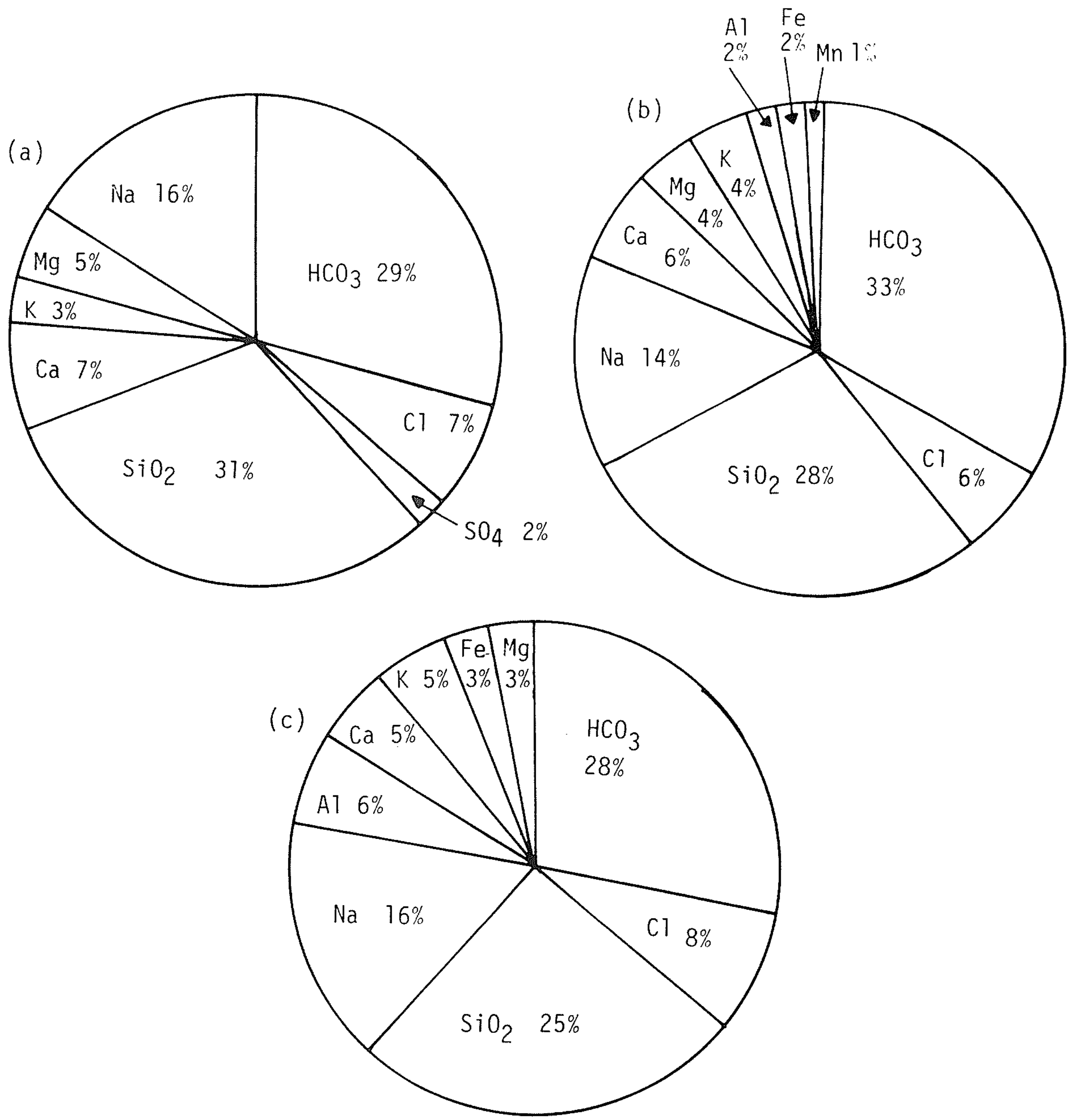
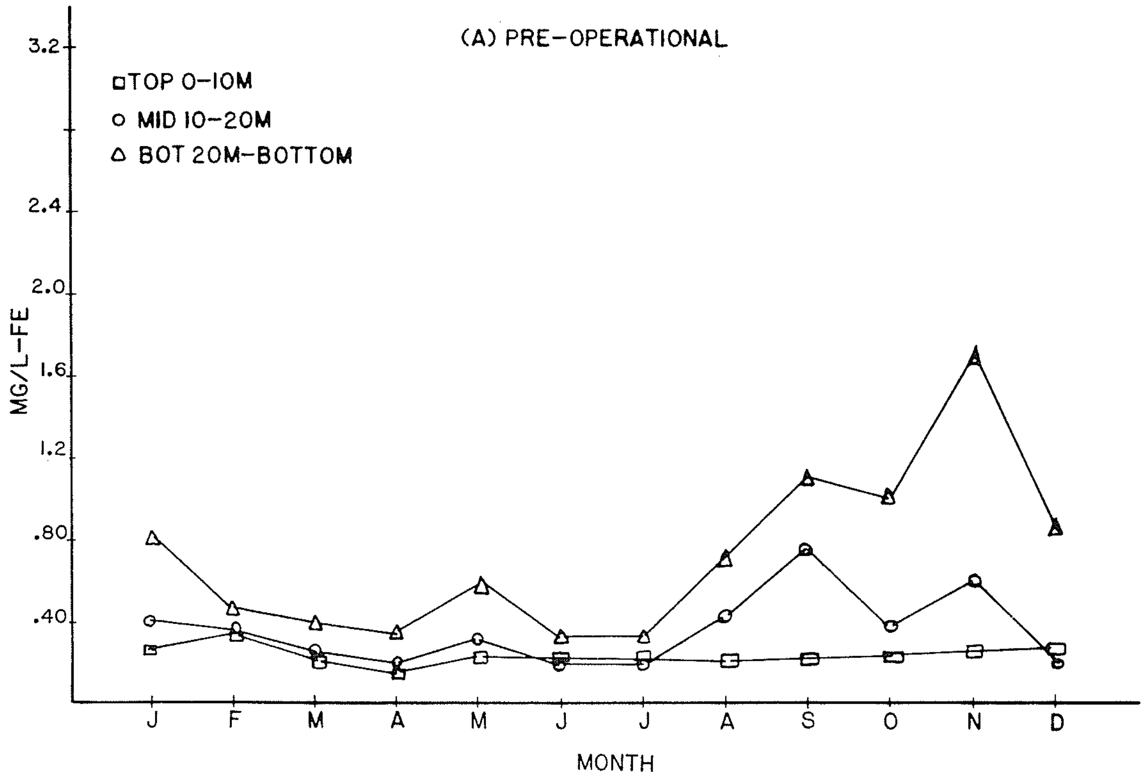


Figure 3-40. Molar percentages of mineral constituents found in Lake Keowee during (a) pre-impoundment (b) operational periods and (c) Lake Jocassee 1974 to 1976.



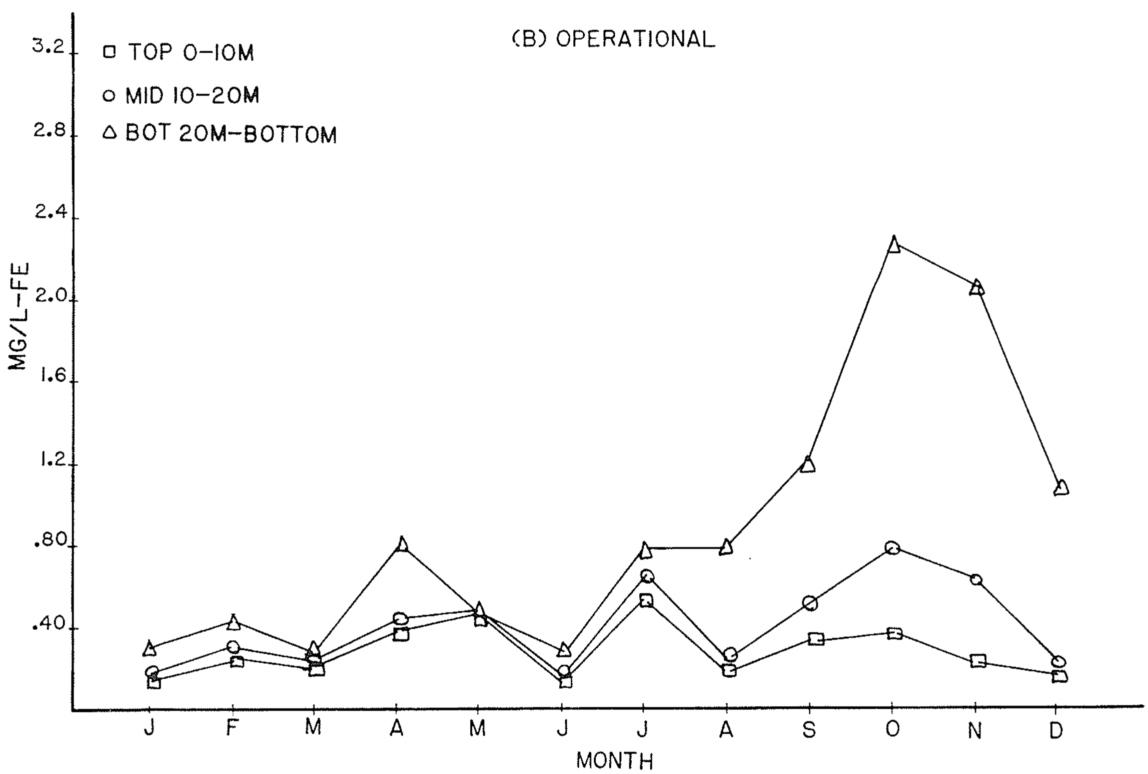


Figure 3-41. Comparison of monthly variations in iron concentrations in Lake Keowee (A) pre-operational (January 1971 through June 1973) and (B) operational (July 1973 through December 1976) study periods in the top, middle and bottom depths of the reservoir.

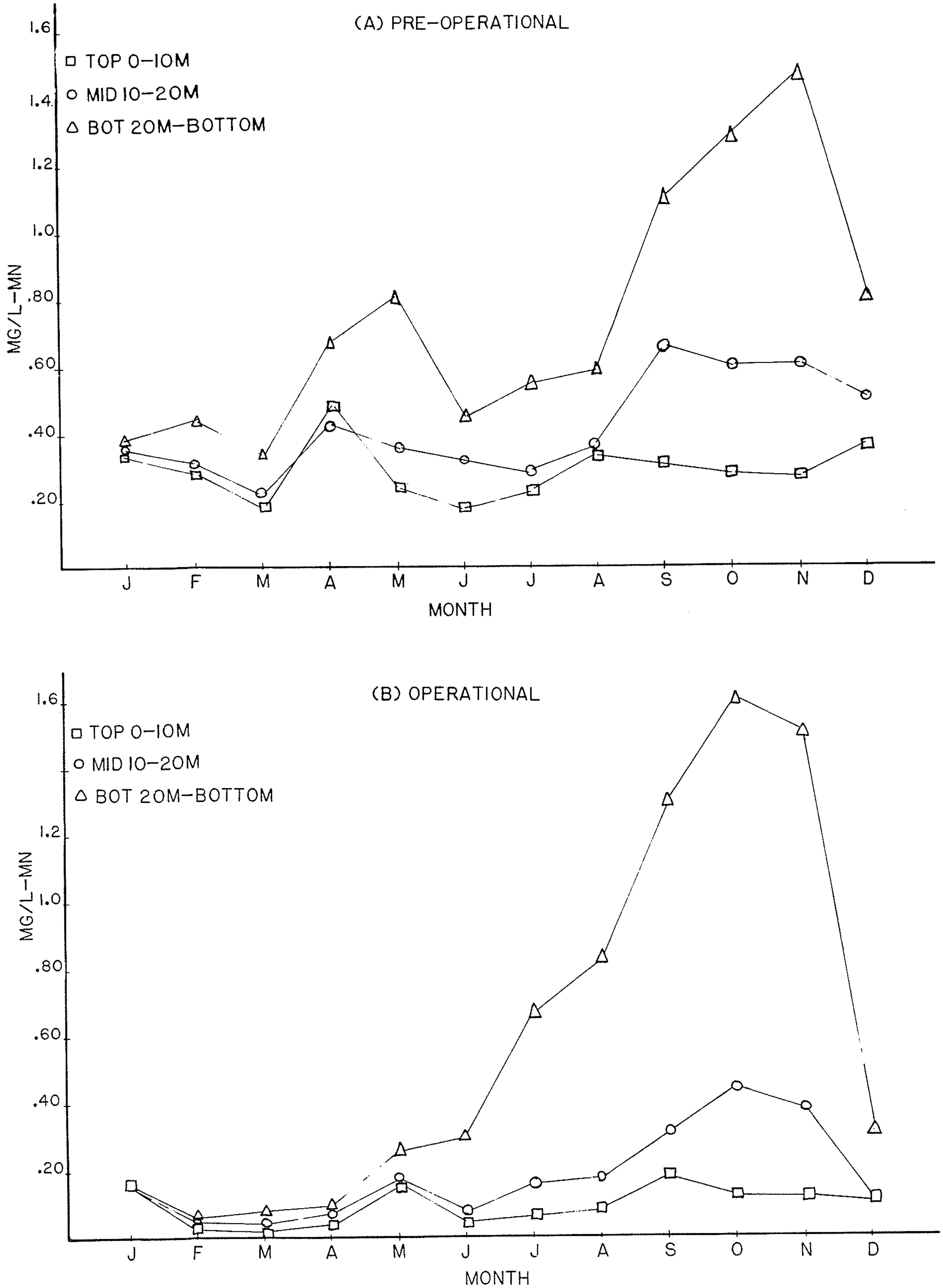


Figure 3-42. Comparison of monthly variations in manganese concentrations in Lake Keowee during pre-operational (January 1971 through June 1973) and operational (July 1973 through December 1976) study periods in the top, middle and bottom depths of the reservoir.

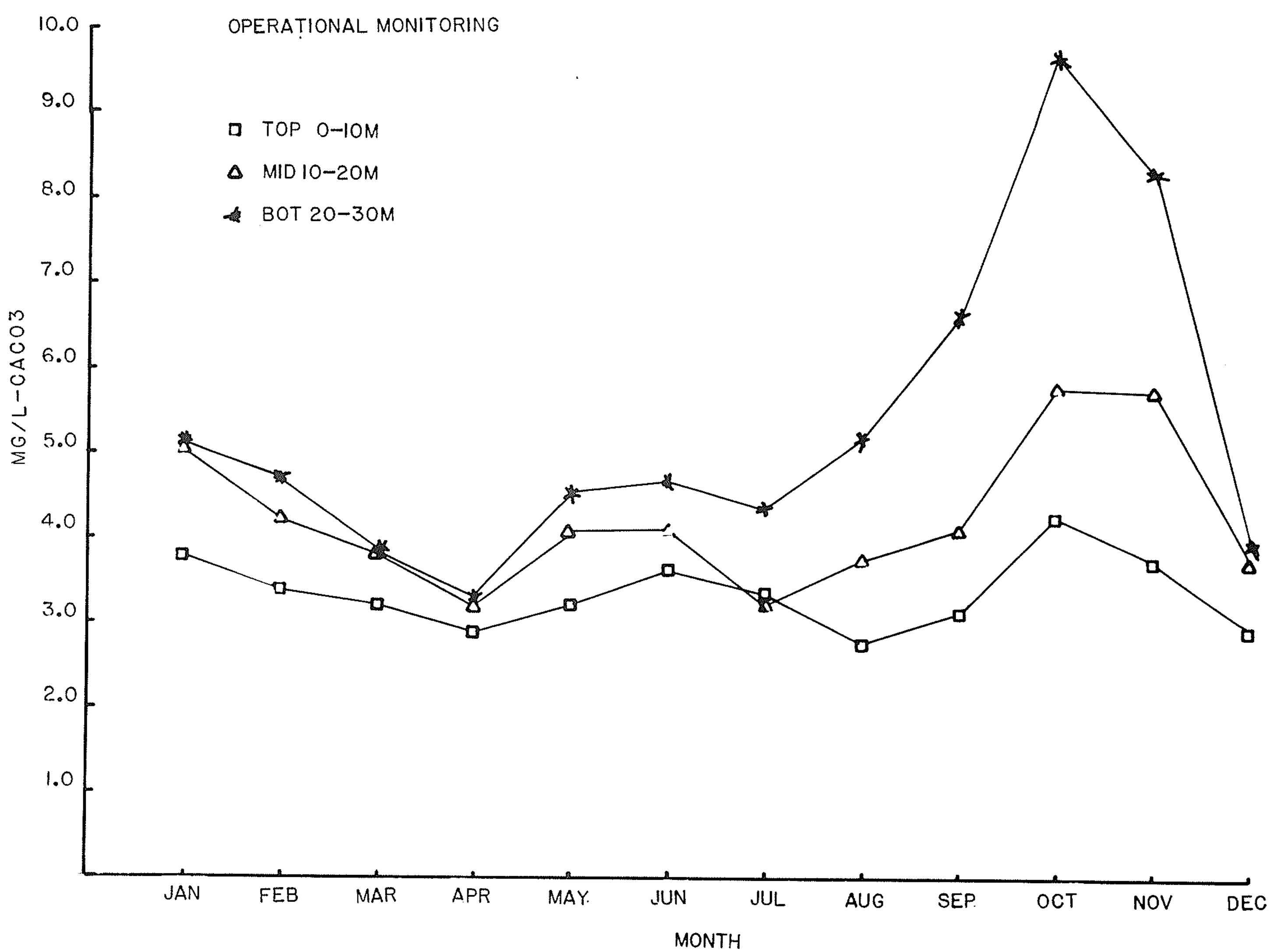
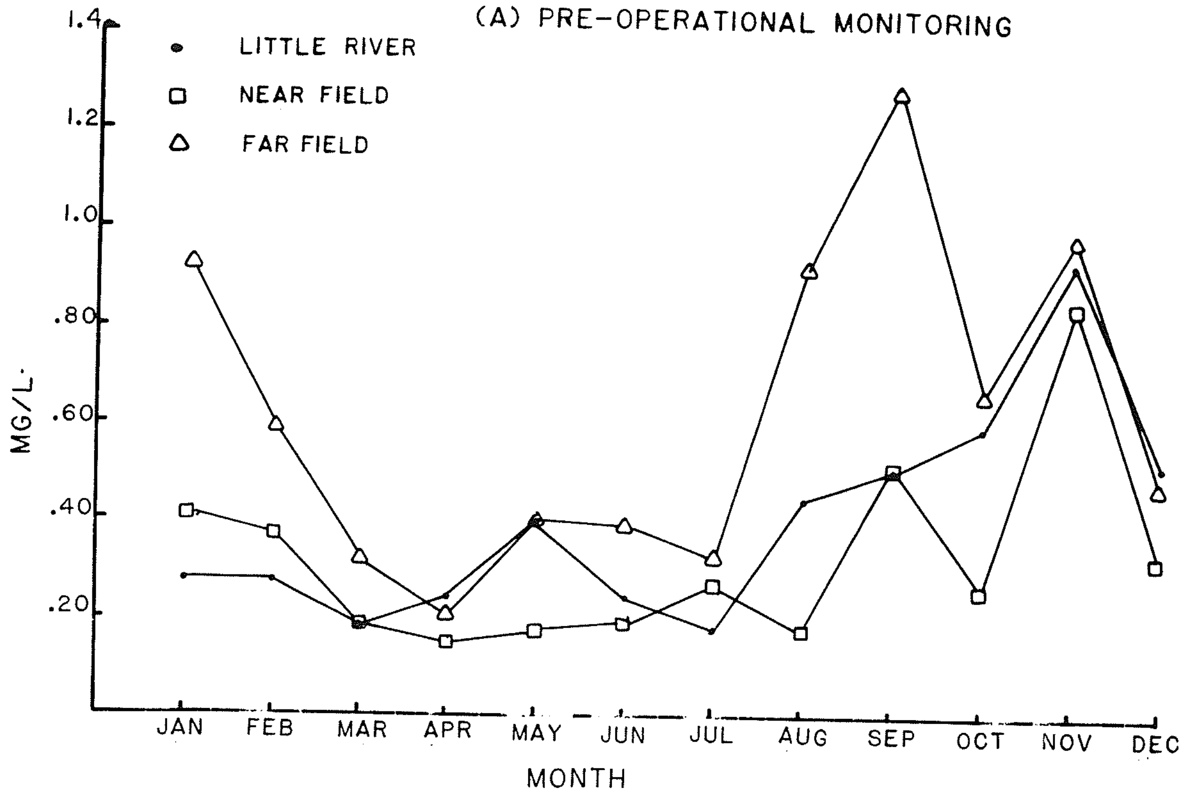


FIGURE 3-43 MONTHLY VARIATIONS IN THE ALKALINITY OF LAKE KEOWEE DURING THE OPERATIONAL STUDY PERIOD IN THE TOP, MIDDLE AND BOTTOM DEPTHS OF THE RESERVOIR.



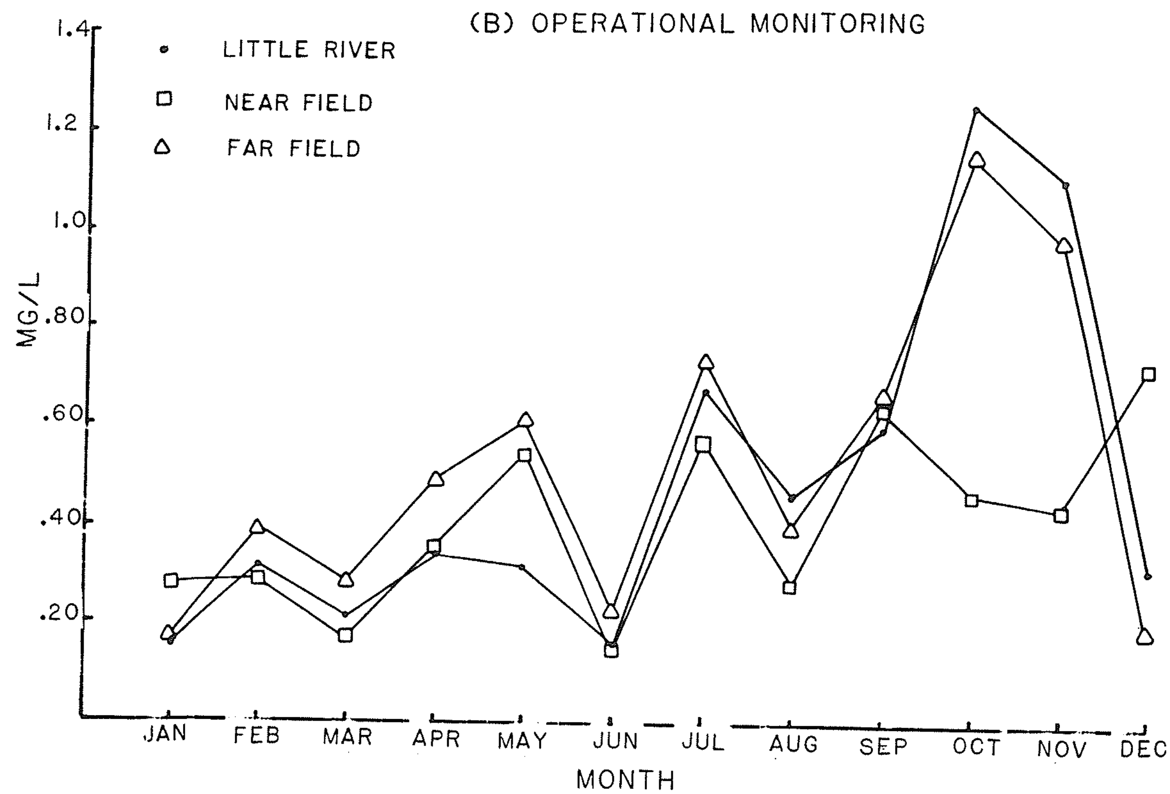


Figure 3-44. Monthly variations in iron concentrations during preoperational and operational study periods in the Little River arm, near field and far field locations on Lake Keowee.

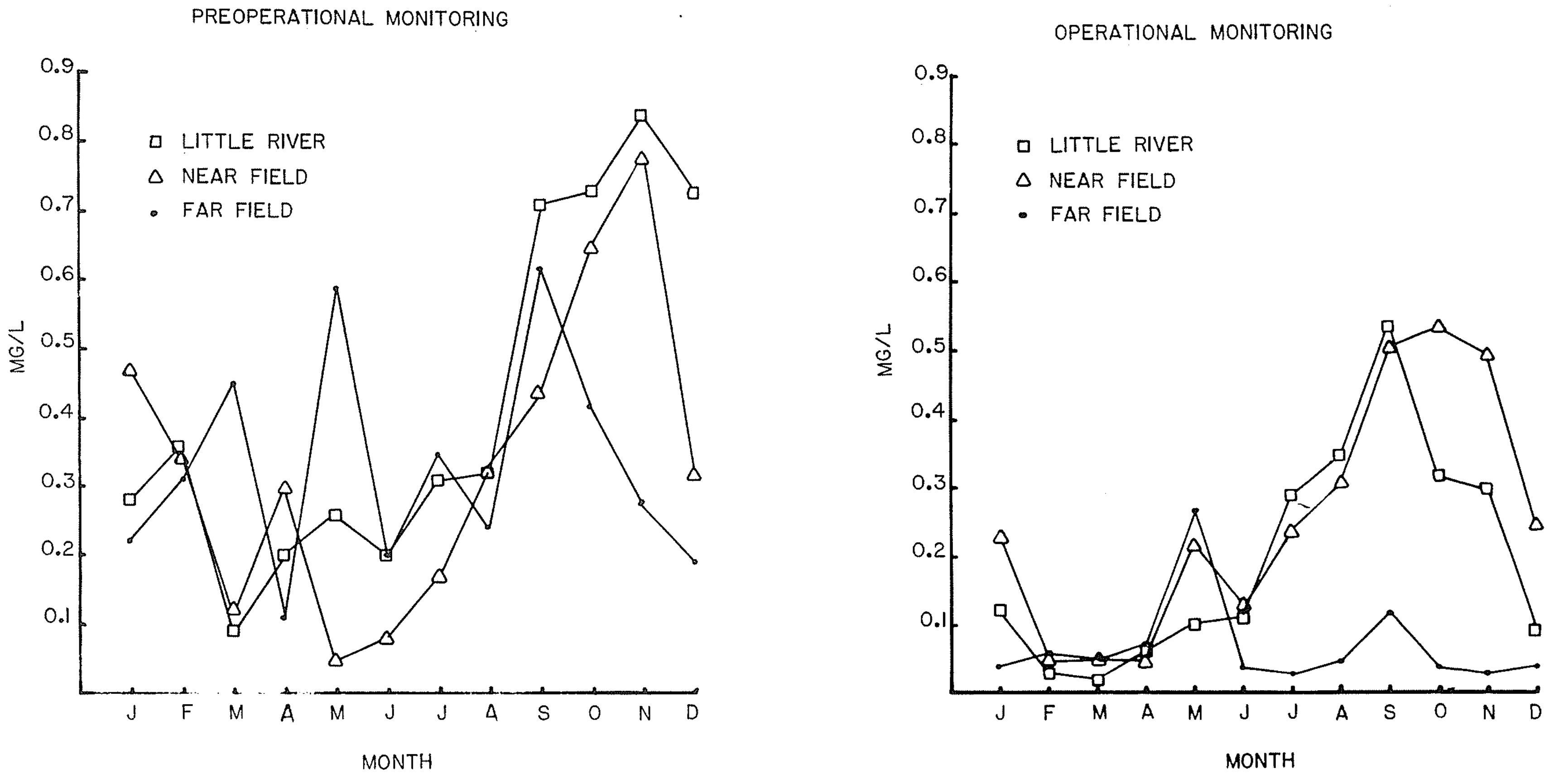


Figure 3-45. Monthly variations in manganese concentrations during pre operational and operational study periods in the Little River Arm, near field and far field locations on Lake Keowee.

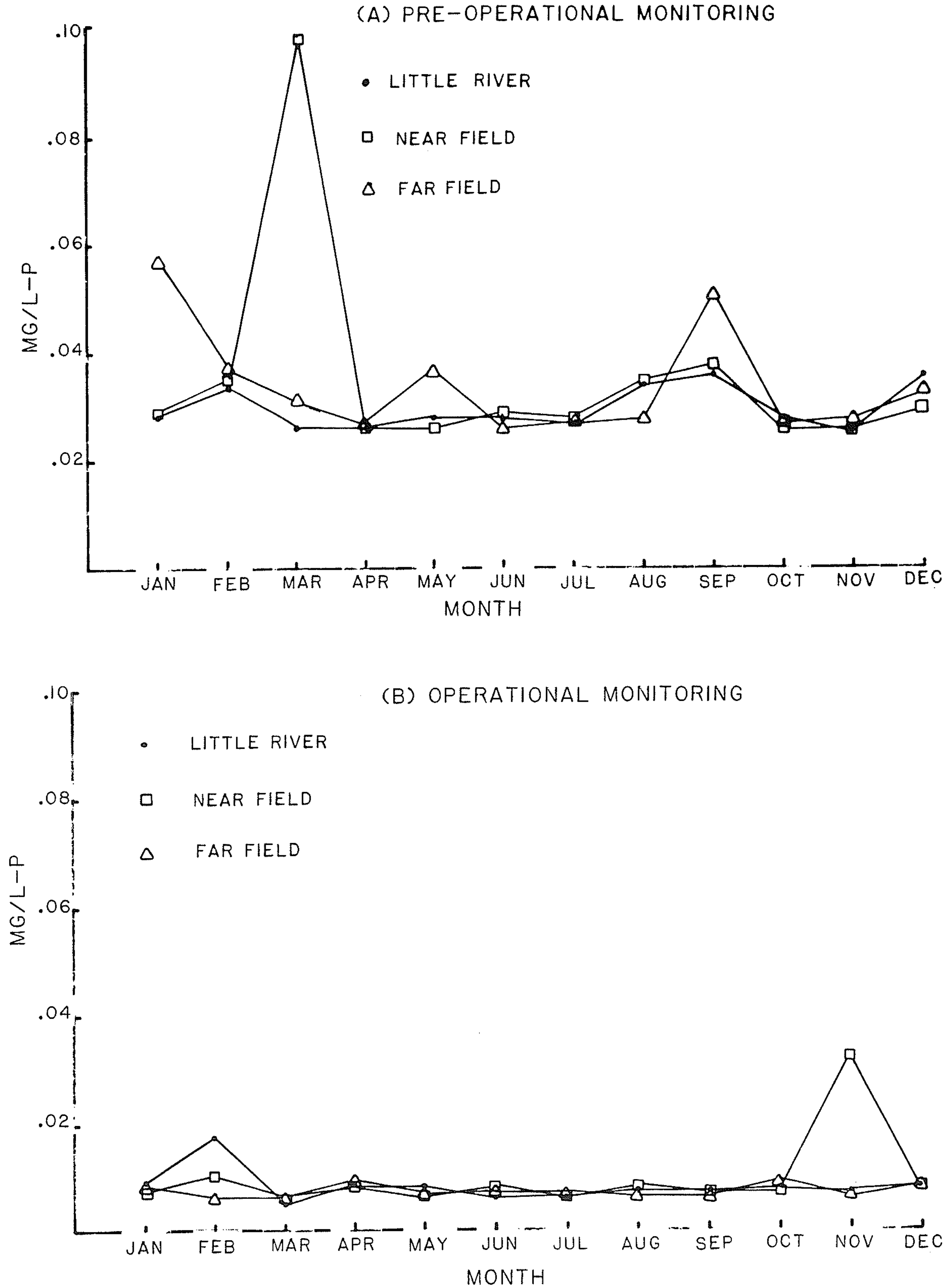


Figure 3-46. Monthly variations in orthophosphate concentrations during preoperational and operational study periods in the Little River arm, near field, far field locations on Lake Keowee.

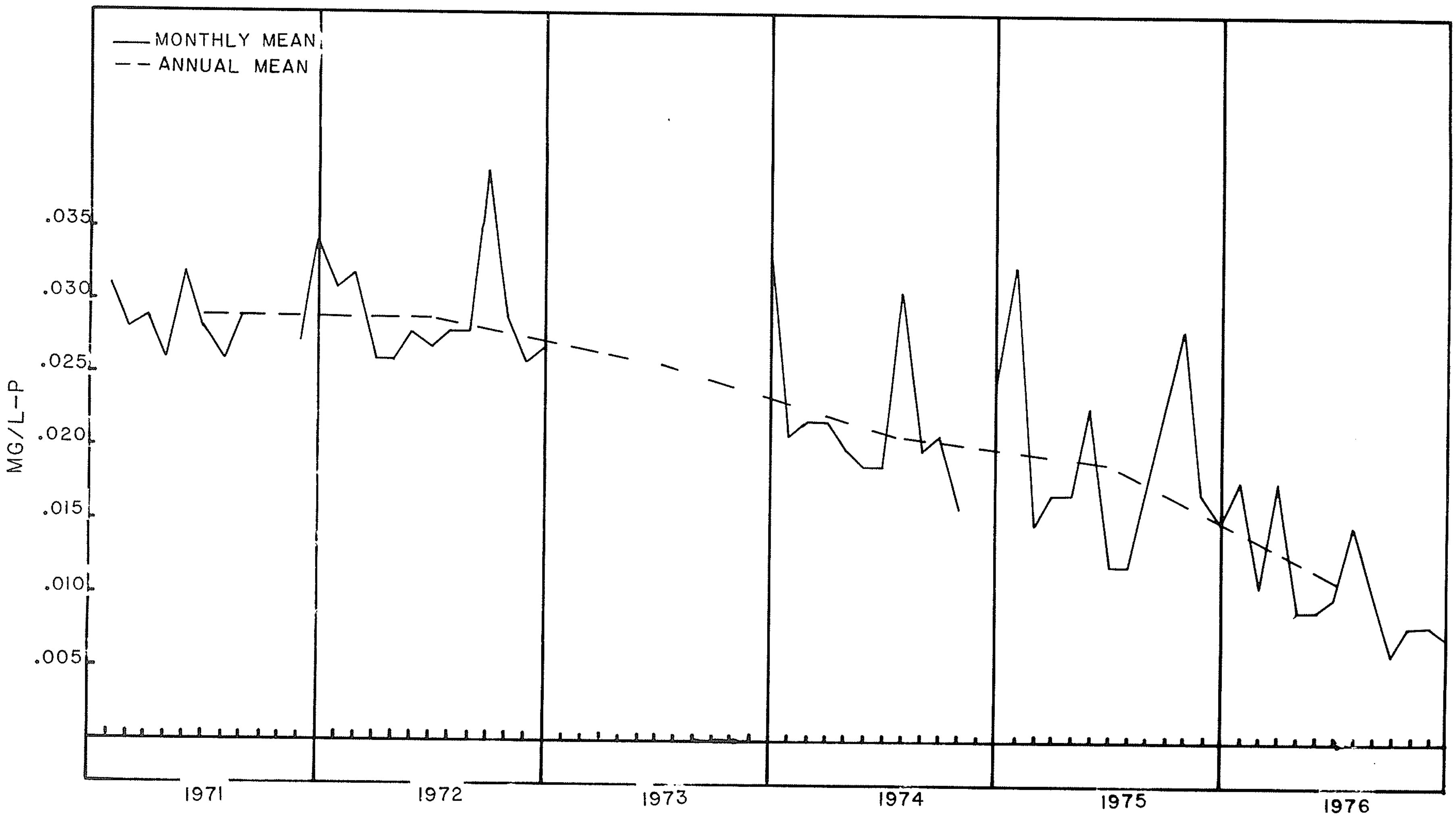


Figure 3-47. Monthly and annual variations in total phosphorus concentrations on Lake Keowee from 1971 through 1976.

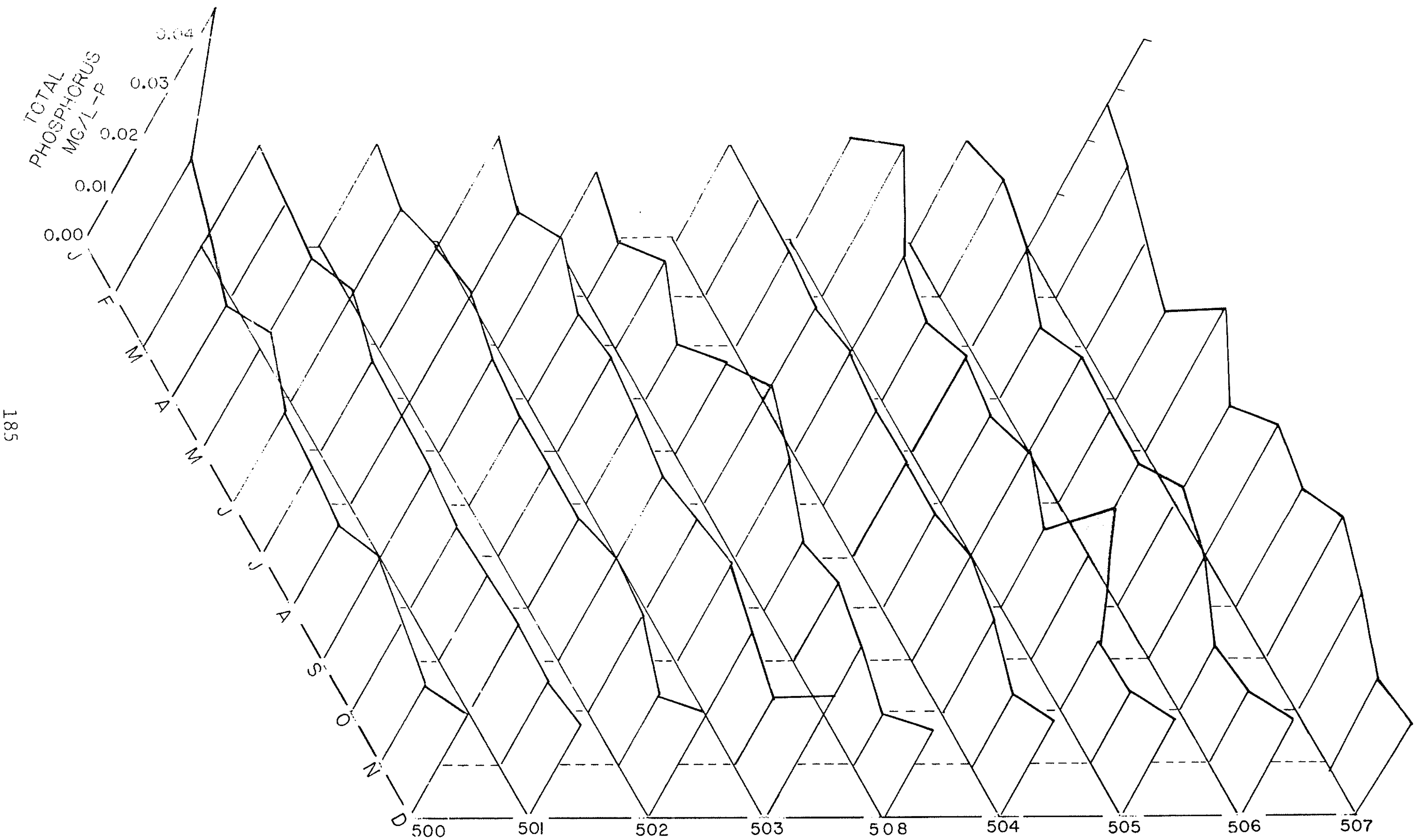


Figure 3-48. Spatial and monthly variations in total phosphorus concentrations from 1971 through 1976 on Lake Keowee.

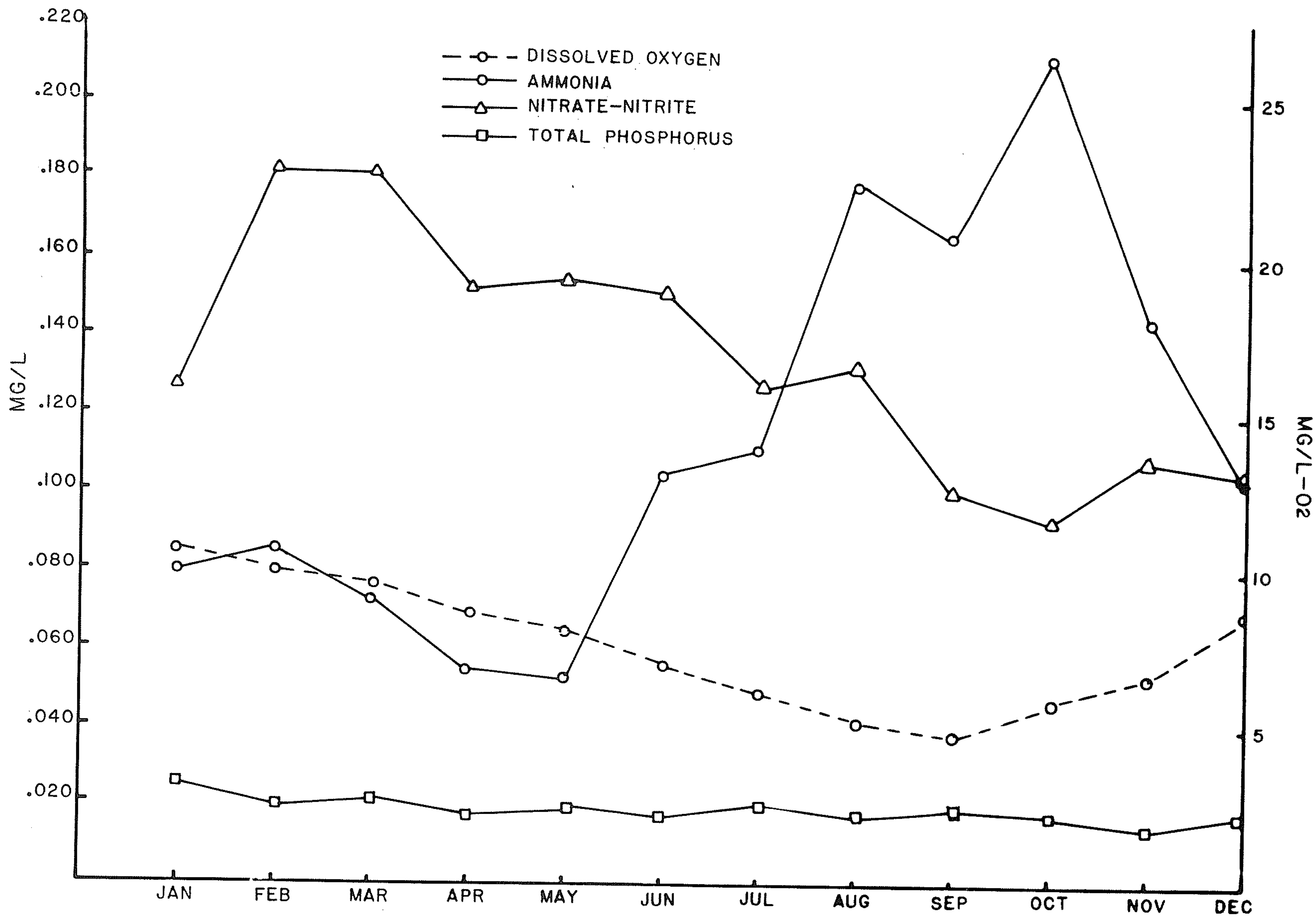


Figure 3-49. Comparison of monthly variations in dissolved oxygen and aquatic nutrient concentrations from 1971 through 1976 at all sampling locations and depths in Lake Keowee.

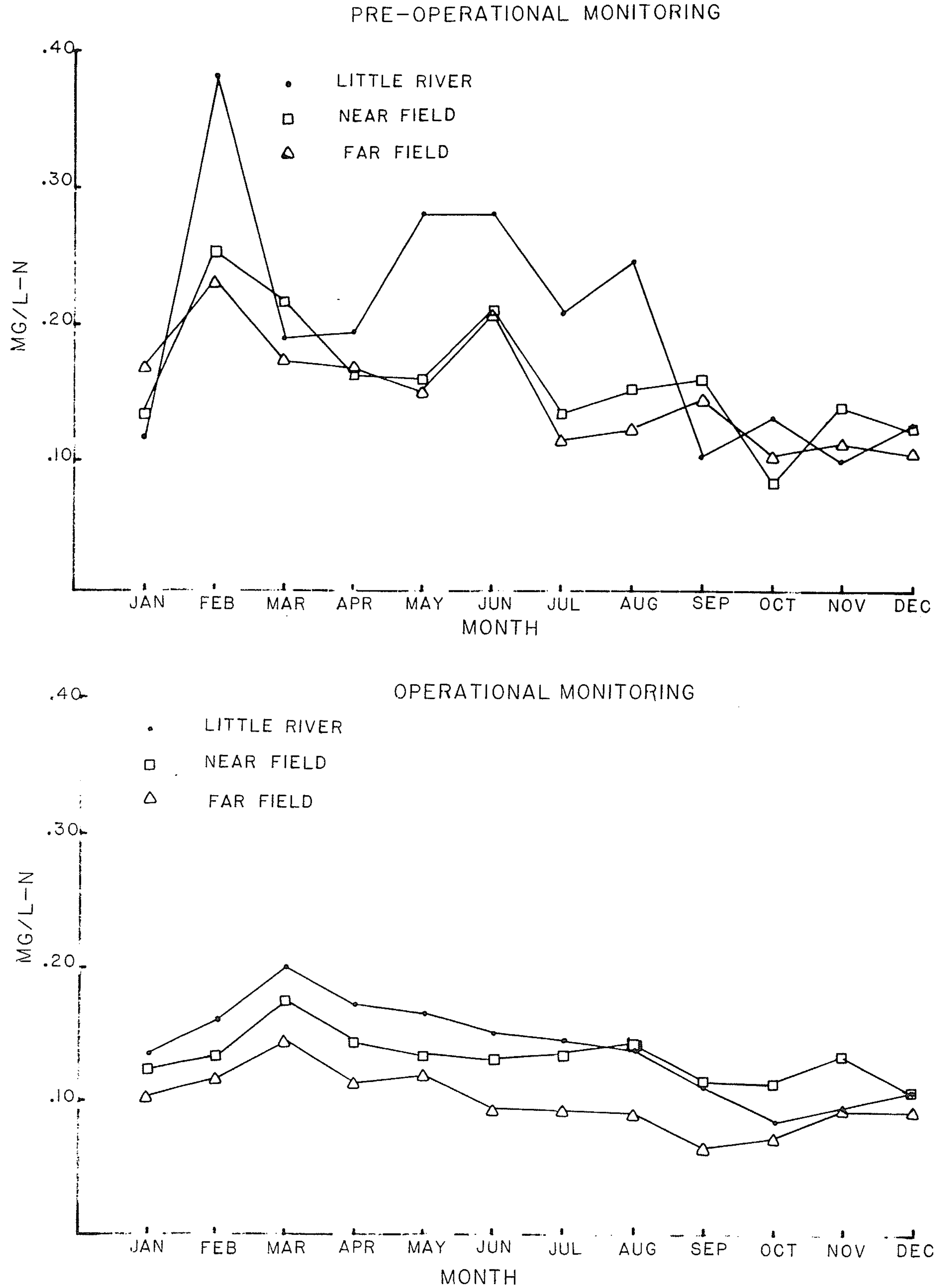


Figure 3-50. Monthly variations in nitrate-nitrite nitrogen concentrations during preoperational and operational study periods in the Little River arm, near field, and far field locations on Lake Keowee.

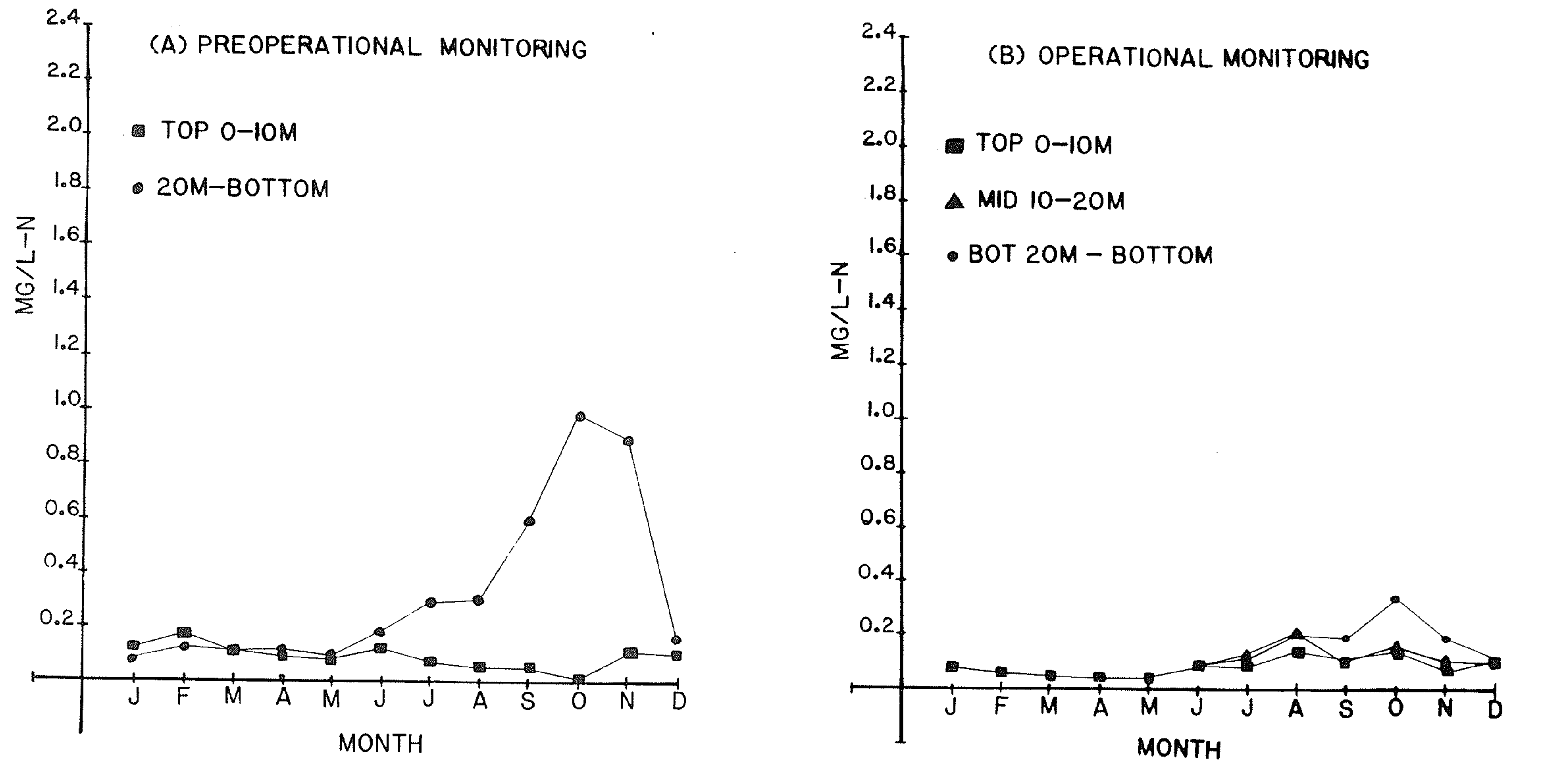
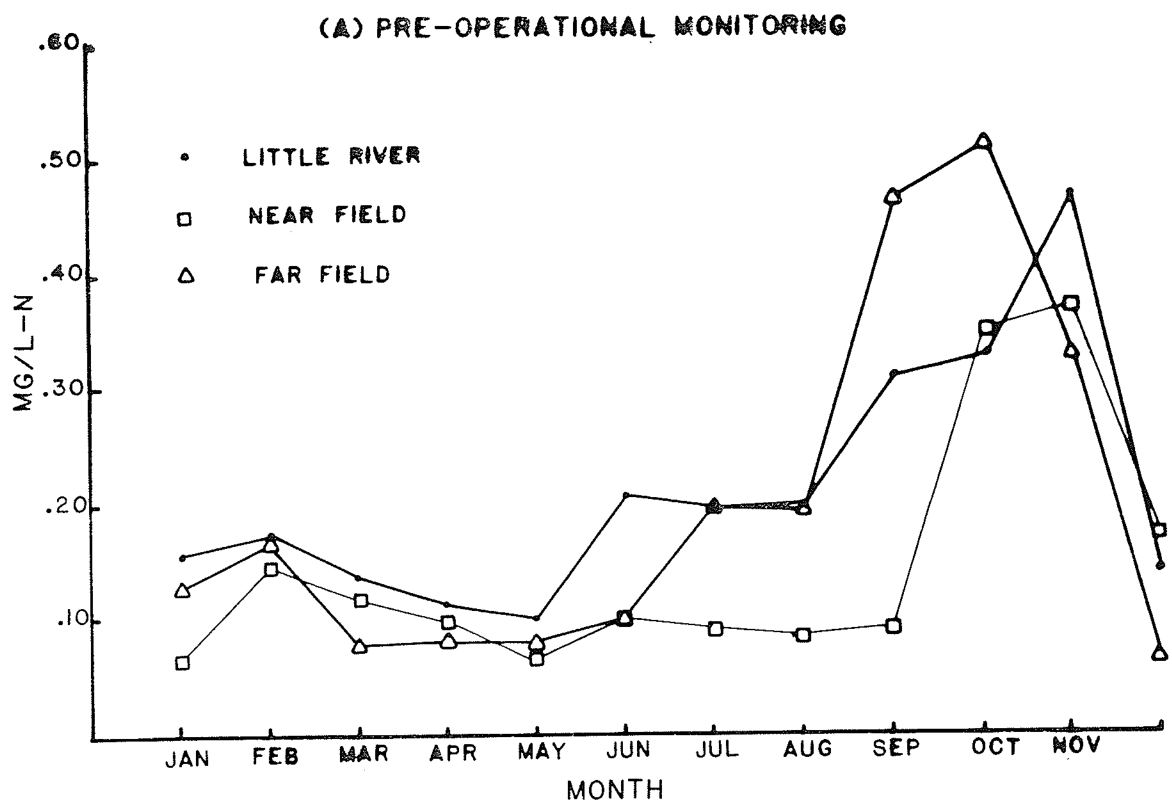


Figure 3-51. Comparison of monthly variations in ammonia concentrations in Lake Keowee during (A) pre operational (January 1971 through June 1973) and (B) operational (July 1973 through December 1976) study periods in the top, middle and bottom depths of the reservoir.



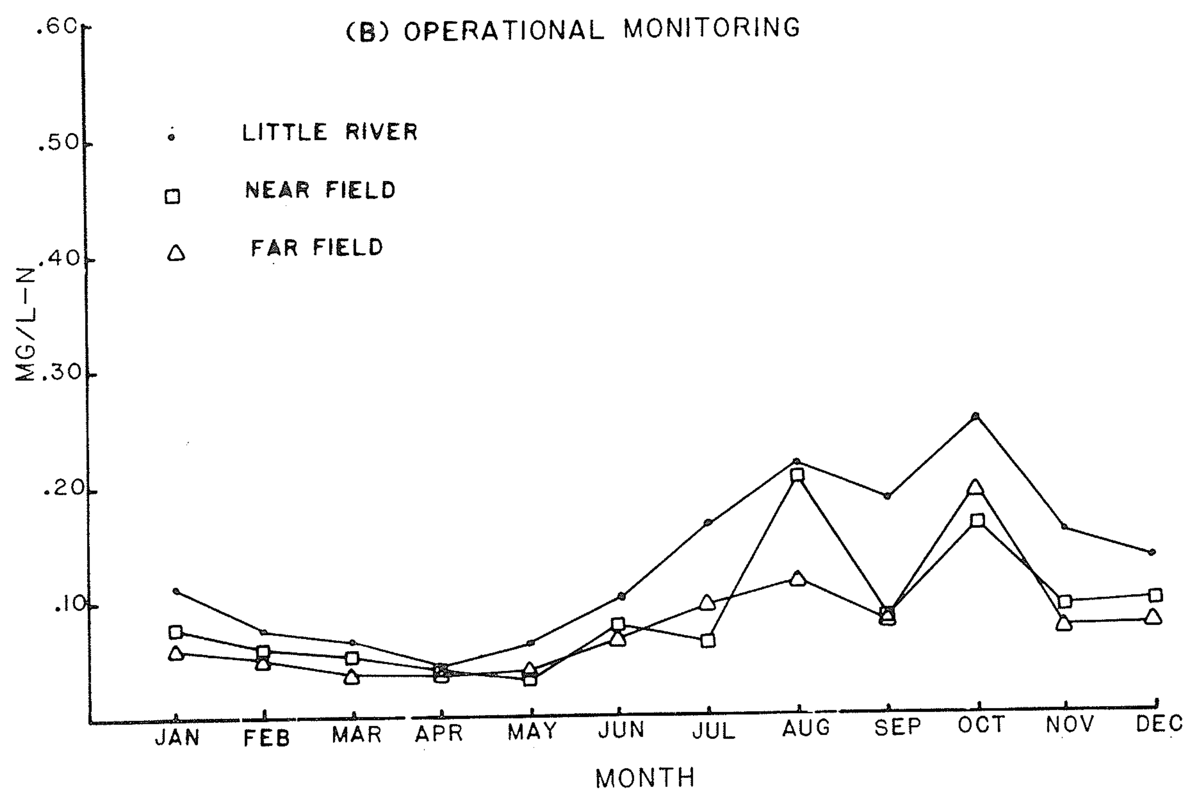


Figure 3-52. Monthly variations in ammonia nitrogen concentrations during preoperational and operational study periods in the Little River arm, near field, and far field locations on Lake Keowee.

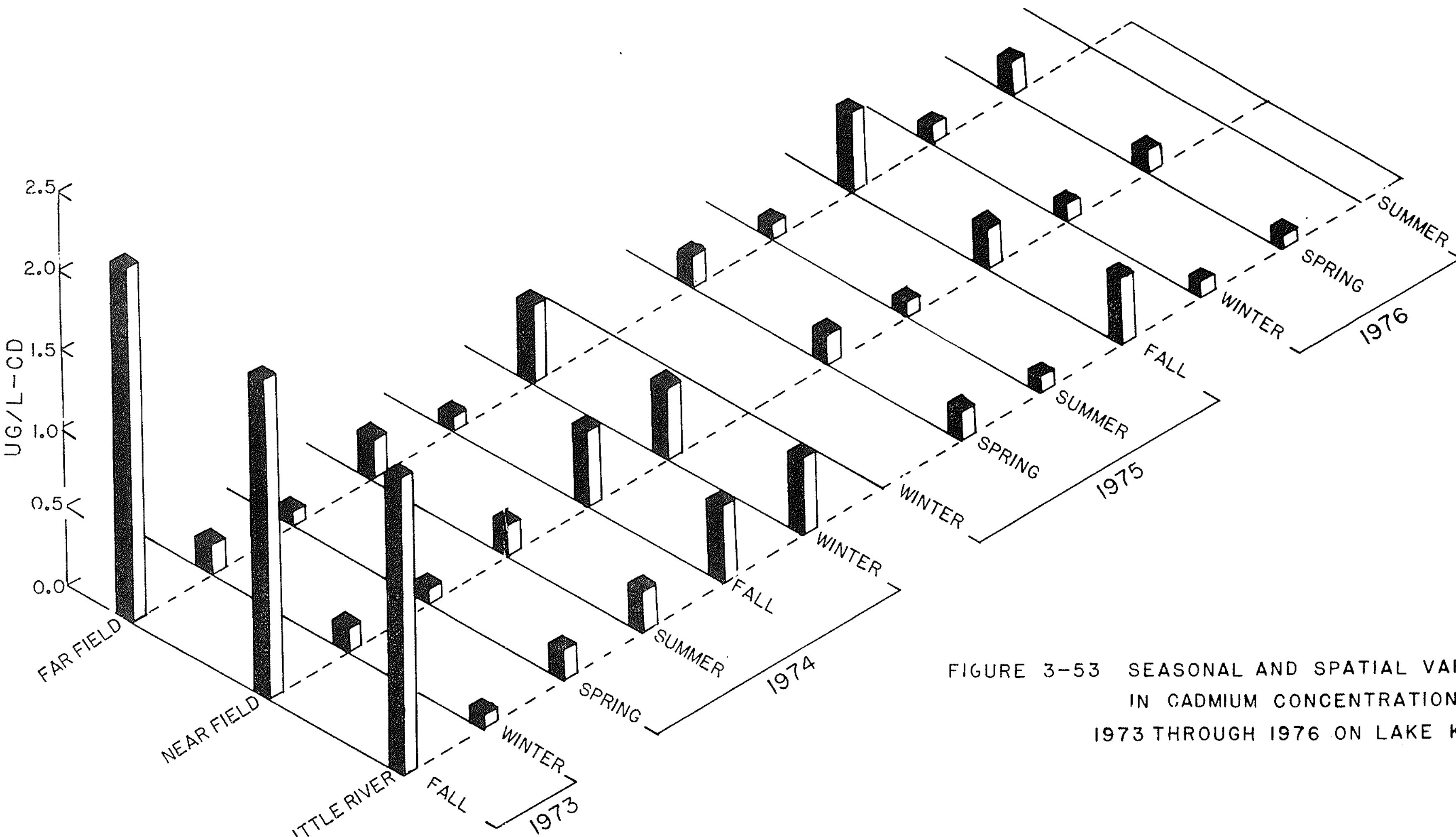


FIGURE 3-53 SEASONAL AND SPATIAL VARIATIONS IN CADMIUM CONCENTRATIONS FROM 1973 THROUGH 1976 ON LAKE KEOWEE.

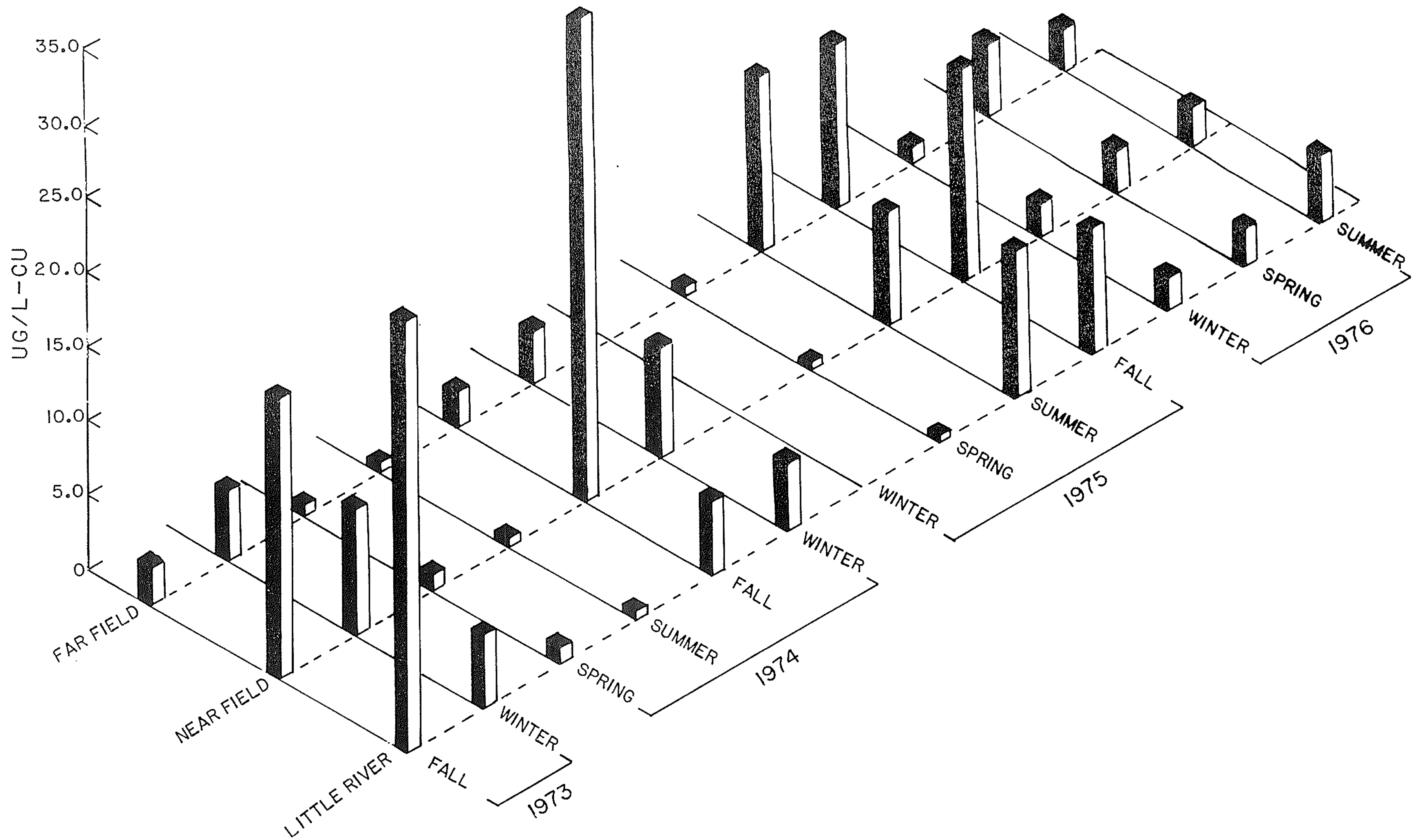


FIGURE 3-54 SEASONAL AND SPATIAL VARIATIONS IN COPPER CONCENTRATIONS FROM 1973 THROUGH 1976 ON LAKE KEOWEE.

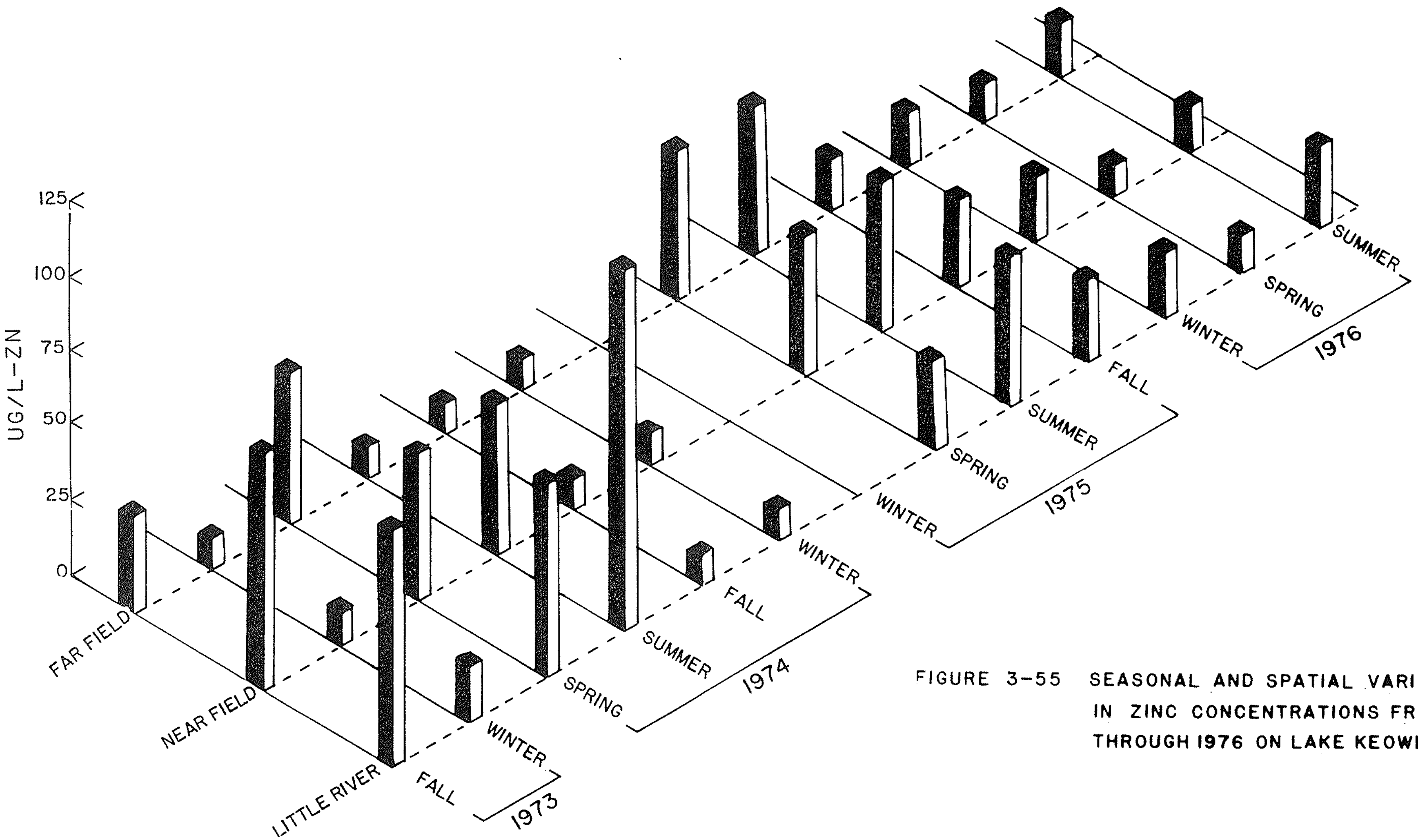


FIGURE 3-55 SEASONAL AND SPATIAL VARIATIONS IN ZINC CONCENTRATIONS FROM 1973 THROUGH 1976 ON LAKE KEOWEE.

CHAPTER 4 PHYTOPLANKTON

INTRODUCTION

Phytoplankton are microscopic plants which, in many instances, form the base of the aquatic food chain. They convert light energy and other basic components to organic matter through photosynthesis for subsequent utilization by heterotrophic organisms. The growth of phytoplankton populations in lake system is regulated primarily by light, temperature, and major and minor nutrient elements. Hutchinson (1967) expressed the importance of phytoplankton in a standing water body: "the detailed consideration of the biology of lakes begins with the phytoplankton, for this assemblage of organisms constitutes the greatest part of the photosynthetic producing level in all but the shallowest of lakes. The whole of the rest of the biological community therefore depends to a very great extent on the planktonic plants." Rodgers (1974) has estimated the importance of phytoplankton as primary producers in Lake Keowee. His findings indicated that planktonic algae accounted for 98% of the primary production within Lake Keowee.

Oconee Nuclear Station (ONS) removes deep water from Lake Keowee for use in its Condenser Cooling Water (CCW) system. Within the CCW system, entrained phytoplankton are subjected to thermal and mechanical stresses. The effect of these stresses on entrained phytoplankton was examined. Temperature elevations recorded in the near-discharge area of Lake Keowee as a result of CCW passage, could potentially change phytoplankton community structure.

The objectives of this monitoring project were: (1) to examine immediate effects of ONS entrainment on phytoplankton; (2) to characterize the seasonal and spatial trends of Lake Keowee phytoplankton and relate these to cooling water use by ONS; and (3) to determine whether the operation of ONS has significantly affected the phytoplankton and if it has, then to determine if the effect has stabilized.

METHODS AND MATERIALS

FIELD AND LABORATORY PROCEDURES

Sampling Location and Frequency

Studies of phytoplankton entrainment in the CCW system were initiated in September 1973 and conducted six times per year through 1976 (Table 4-1). There were four sampling locations including a location approximately five meters deep in front of the intake structure (530.0), Unit 1 precondenser water tap (530.3), postcondenser water tap (530.6), and a location approximately ten meters deep near the discharge structure (530.9).

Phytoplankton collections on Lake Keowee were initiated in July 1973 at six locations, 500.0, 503.0, 505.0, 506.0, 508.0, and 509.5 (Figure 1-1). The first two locations were located in the Little River arm and the second two were situated in the Keowee River arm of the reservoir. Location 509.5 was within the 1.5 km intake canal, approximately 100 m from the ONS intake structure. The discharge sampling location (508.0) was located approximately 100 m from the discharge structure. In 1974, Location 502.0 (lake-side of the skimmer wall) and Location 508.5 (between Keowee hydro station and ONS discharge cove) were added to assess the effects of ONS on phytoplankton in the receiving water. Sampling was conducted every two months except for monthly sampling from July 1974 through July 1975 (Table 4-1).

In the receiving water study, two types of samples were obtained from each location, the euphotic zone composite (EZC) and the lower depth sample (LSD). Euphotic zone samples were used to estimate phytoplankton standing crops in areas that potentially could be affected by the ONS discharge. Lower depth samples were used to estimate a vertical gradient in phytoplankton abundance. Euphotic zone sampling was based on the depth of one percent of surface light, using a Montedoro-Whitney solar illuminance meter (LMD-8A). The EZC samples were collected with a Van Dorn water bottle by compositing one liter of water from each of three depths: (1) 0.3 m; (2) a depth midway between the surface and the depth of one percent light level; and (3) at the one percent surface light depth. The LSD samples were collected approximately one meter off the lake bottom with a Van Dorn water bottle.

Standing Crop Estimates

Standing crop represents an instantaneous quantity of organisms that can be expressed in terms of density, biovolume, and/or chlorophyll. Density (population numbers per unit volume) tends to overemphasize the importance of small organisms, while biovolume (population volume per unit volume) overemphasizes the importance of large organisms (Odum 1971). For this reason, phytoplankton density and biovolume were both used to assess phytoplankton standing crops. Chlorophyll content is another quantitative measure of the phytoplankton; however, it provides no information on the component species of the phytoplankton.

Algal density and biovolume estimates were made from samples collected at entrainment and lake locations. Population samples collected in 1973 were analyzed by the membrane filter technique [American Public Health Association (APHA) 1971]. This method was replaced due to identification difficulties. From January, 1974 to December, 1976, 950-ml samples were preserved with 15 ml of M^3 stain fixative (Meyer 1971). The samples were settled in glass bottles for 96 hr, after which the supernatant was siphoned off, and the concentrate was resuspended in a 125-ml glass settling bottle (Weber 1973). After another 48 hr, the supernatant was siphoned off and the concentrate was resuspended in a 32-ml vial. After a 48-hr setting period, the supernatant was siphoned off leaving 5 ml of concentrated sample. Each transfer was followed by two distilled water rinses of the sample bottle and each rinse was added to the resuspended concentrate. The final concentrate was used to fill a Palmer-Maloney nannoplankton chamber (Palmer and Maloney 1954) from which quantitative counts were made. At least 100 cell units were counted in each sample. Cell units were defined as single cells, single colonies, or 18-μm filamentous lengths (all diatom chains were subdivided and enumerated by single cells). Algal biovolumes (mm^3/m^3 of water) were estimated from calculated densities (units/m^3 of water) and cell volumes (mm^3) for each species. Cell volumes were calculated from average measured dimensions fitted to geometric formulae for solid shapes simulating the algal taxon. Diatom identifications were made at 1250X on hyrax slide mounts (Weber 1971) using a compound phase microscope.

Taxonomic references used for algal identification included Bourrelly (1968), Cocke (1967), Eddy (1930), Fott (1969), Huber-Pestalozzi (1968), Hustedt (1930), Kim (1967), Patrick and Reimer (1966), Prescott (1962), Skuja (1948), Smith (1950), Taft and Taft (1971), Tiffany and Britton (1971), Weber (1971), and Whitford and Schumacher (1973). Duke Power Company retained Dr. L. A. Whitford, North Carolina State University, Raleigh, NC, as a consultant for algal taxonomic assistance, and Dr. C. W. Reimer, Philadelphia Academy of Sciences, Philadelphia, PA, for diatom taxonomy. An algal reference collection is maintained within the Environmental Sciences Unit Laboratory.

Chlorophyll samples for entrainment and receiving water studies were collected from water common to the population samples. Two hundred fifty milliliters of water was filtered through a glass fiber filter to which magnesium carbonate was added to prevent chlorophyll deterioration. Chlorophyll was extracted from the filters by maceration with a tissue grinder in 90% acetone, and pigments were analyzed fluorometrically according to the method described by Strickland and Parsons (1972).

Primary Productivity

The entrainment sampling procedures included primary productivity estimates using Carbon-14 uptake rates to measure community metabolism. Paired light and dark 125-ml glass reagent bottles were filled with sample water, inoculated with $NaH^{14}CO_3$ (1-2 μCi), and analyzed by the procedures of Strickland and Parsons (1972). One half of the paired bottles collected at the two entrainment locations (530.0 and 530.9) were incubated at the intake temperature (lower mean incubation temperature) in a controlled-temperature light incubator. The other half were incubated in a similar chamber and maintained at the discharge temperature (higher mean incubation temperature) measured at the time of collection. Measurements of pH and total alkalinity (APHA 1971) were performed as soon as possible on samples from each location. Total available inorganic carbon (TAIC) present was calculated for each sample with the equation: TAIC = total alkalinity X C_F [a conversion factor modified by Saunders et al. (1962)].

Carbon assimilation ratios (carbon uptake rate per unit chlorophyll) were used to estimate specific primary productivity of entrained phytoplankton. Entrainment effects were separated into thermal, mechanical, and total effects. Thermal effects were assessed by a comparison of assimilation ratios of intake samples incubated at the higher mean incubation temperature (MIT) to intake samples incubated at the lower MIT. Mechanical effects were evaluated by a comparison of assimilation ratios of discharge samples incubated at the higher MIT to intake samples incubated at the higher MIT. The total effects were assessed by comparing assimilation ratios of the discharge samples incubated at the higher MIT to intake samples incubated at the lower MIT. Similar experimental designs were used to assess power plant entrainment effects at Tradinghouse Creek Reservoir, Texas (Lind 1975) and Indian River Estuary, Delaware (Brooks 1972).

STATISTICAL ANALYSES

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1969) was performed on replicated algal density, biovolume and chlorophyll data. For entrainment studies, data meeting the assumptions of analysis of variance (ANOVA) were tested with a two-factor ANOVA to examine location and date differences (Sokal and Rohlf 1969) at the $\alpha = 0.05$ level. Assimilation ratio data were analyzed using Friedman's non-parametric test (Conover 1971). For receiving water studies, a three-factor ANOVA was performed on density, biovolume and chlorophyll data to examine lake area, months and year differences. When a significant interaction was present in ANOVA, a simple main effects test was used to isolate the times when significant location differences existed (Keppel 1973). A least significant difference test was used to identify the significantly different means (Keppel 1973). Data from 1973 were not included in the statistical analyses because sample processing methods were different from those used from 1974 through 1976. A stepwise multiple regression procedure (Draper and Smith 1966) was used to select variables which were the best predictors of fluctuations in phytoplankton abundance. All statistical testing was performed by means of the Statistical Analysis System computer programs of Barr et al. (1976).

RESULTS AND DISCUSSION

ENTRAINMENT STUDY

Phytoplankton Standing Crops

Mean phytoplankton densities for each sampling date and year are presented in Table 4-2. The highest mean densities for each year were recorded in June 1974, September 1975 and July 1976. The lowest mean densities for each year were observed in January 1974, November 1975 and May 1976. The relatively low concentrations of algae in the CCW throughout the study period were the result of the deep water entering the intake canal from under the skimmer wall near Location 502.0. The deep water had low densities in comparison to those present in the euphotic zone of the lake (Figure 4-1 and 4-2); hence, intake populations were similar to those found at 502.0 LSD (Figures 4-2 and 4-3). The class compositions of samples from Locations 530.0 and 502.0 LSD illustrated similar seasonal trends and were primarily composed of Bacillariophyceae (diatoms) and Chlorophyceae (green algae). Myxophyceae (blue-green algae) never comprised more than 16% of the total density, and usually were not observed in the samples.

Maximum mean phytoplankton biovolumes for each year were recorded in December 1974, September 1975 and November 1976 (Table 4-2). The lowest biovolumes for each year were observed in March 1974, October 1975 and May 1976. The dominant class comprising most of the intake and discharge biovolume was Bacillariophyceae (Figures 4-3 and 4-4). Other classes which occasionally contributed large numbers to the biovolume estimates were Chlorophyceae, Dinophyceae (dinoflagellates), Chloromonadophyceae, and Cryptophyceae. Density and biovolume peaks did not always coincide because the occurrence of one large species in a sample could substantially increase the total biovolume in the sample. Examples of large species which frequently comprised the largest percent of a sample's biovolume were Rhizosolenia eriensis (diatom), Peridinium wisconsinense (dinoflagellate), Staurastrum pentacerum (green), and Gonyostomum depressum (Chloromonadophyceae).

The mean total chlorophyll concentrations for sample dates and years are presented in Table 4-2. Highest chlorophyll estimates were recorded in the summer months. Peak concentrations occurred in June 1974, and September of 1975 and 1976. The lowest chlorophyll estimates were observed in December 1974, February and November 1975, and July and November 1976.

Trends for density, biovolume and chlorophyll estimates between the intake and discharge locations were similar (Figures 4-3 and 4-4). Results of a two-factor ANOVA for density and biovolume indicated no significant differences among CCW sampling locations ($p>0.75$). A significant interaction occurred in the chlorophyll data (Table 4-3). A simple main effects test for chlorophyll indicated significant differences among locations on three dates, which was attributed to patchiness of intake algae. Significant date differences occurred for all three variables. Date differences were the result of seasonal periodicity of intake population abundances (Figure 4-3).

Phytoplankton Metabolism

Mean assimilation ratios for each date and location are presented in Table 4-4. Friedman's ANOVA of assimilation ratios indicated no significant differences between locations for thermal effects ($p>0.36$), mechanical effects ($p>0.36$) and total CCW passage effect ($p>0.83$). Therefore, ONS operations appeared to have no direct effect on entrained phytoplankton productivity. There were significant differences between dates which could be attributed to natural seasonal variation in Lake Keowee phytoplankton (Figures 4-1 through 4-4).

Studies of the effects of Marshall Steam Station on phytoplankton productivity in Lake Norman, NC (Smith et al. 1974), showed little evidence for loss of productive capacity due to mechanical effects. However, larger increases in productivity in cooler months and much smaller increases in summer months resulted from thermal increases. Lind (1975) found that total plant effects had an immediate stimulatory effect on photosynthesis except at discharge temperatures of 42 C or higher, when the effect was inhibitory. When thermal effects alone were analyzed, only three dates in Lind's two-year study showed a significant thermal effect on photosynthesis. Brooks (1972) showed that primary production rates at the discharge were stimulated by thermal elevations of six to seven degrees Celsius when ambient temperatures were below 22 C and inhibited when ambient temperatures exceeded 22 C.

Gurtz and Weiss (1972) investigated the effects of entrainment on phytoplankton productivity at Allen Steam Station, Lake Wylie, NC. They found inhibitions of primary productivity at ΔT's of 10, 20 and 30 F° (5.5, 11.0 and 16.5 C°, respectively), regardless of the initial temperature. When intake temperatures exceeded 83 F (28.5 C) and the ΔT was either 10 or 20 F° (5.5 or 11.0 C°, respectively) there was a trend toward greater inhibition; and with increasing intake temperatures, there was a greater inhibition at a ΔT of 30 F° (16.5C°).

At ONS, the entrained phytoplankton were probably in poor physiological condition since they were in the aphotic zone of Lake Keowee for a period of time before entrainment at ONS. Most phytoplankton, as they sink into the aphotic zone of a reservoir, are unable to photosynthesize and soon die (Round 1973). Another consideration in explaining differences between the results of ONS phytoplankton entrainment studies and other studies was that of temperature. The measured CCW intake temperatures ranged from 10.5 to 24.5 C whereas the lower MIT's ranged from 11 to 24 C. The measured ΔT's at ONS ranged between 0 and 9.5 C throughout the study, with a mean ΔT of six degrees Celsius. The MIT ΔT's ranged from three to ten degrees Celsius during the study, with the same mean ΔT of six degrees Celsius (Table 4-4). Thus, the intake temperatures and ΔT's at ONS were never as high as some of those observed in the experiments of Gurty and Weiss (1972). If discharge temperatures at ONS had reached relatively high levels, some immediate effects on phytoplankton productivity at ONS would have been expected.

RECEIVING WATER STUDY

Dominant Phytoplankton

Chlorophyceae and Bacillariophyceae typically comprised a large percentage of the EZC cell densities at Locations 500.0, 506.0 and 508.5 (Figures 4-5 through 4-7). Green algae usually dominated densities during the summer and early fall, whereas diatoms were winter and spring dominants. Green algae which dominated densities were *Ankistrodesmus* spp., *Cosmarium* spp., *Dictyosphaerium* spp., *Monoraphidium setiforme*, and unidentified coccoid greens. Dominant diatom taxa were *Cyclotella stelligera*, *Eunotia zasuminensis*, *Melosira distans*, *Melosira italica*, and *Rhizosolenia eriensis*. Other classes and taxa that occasionally dominated densities were: (1) Myxophyceae represented by *Agmenellum quadriduplicatum* and *Anacystis* spp.; (2) Chrysophyceae represented by *Chromulina* spp. and *Dinobryon* spp.; (3) Cryptophyceae as *Chroomonas acuta* and *Cryptomonas ovata*; and (4) Dinophyceae represented mostly by *Peridinium inconspicuum*. Seasonal variation of percent class composition of density at the three locations appeared similar. Algal biovolumes were usually dominated by diatoms and dinoflagellates (Duke Power Company 1974a, b; 1975a, b; 1976a). Taxa which usually produced the greatest biovolumes were *P. inconspicuum*, *P. wisconsinense*, *C. stelligera*, *R. eriensis*, and *M. distans*.

The EZC phytoplankton populations at Location 508.5 (Figure 4-7) had a higher percent composition of green algae on most sampling dates than either intake (530.0) or discharge (530.9) populations (Figures 4-3 and 4-4) where diatoms usually comprised a greater proportion of the density. The predominance of green algae at Location 508.5 was a good indication that CCW discharge mixed rapidly with receiving waters.

Temporal Variation

The phytoplankton of Lake Keowee were sparse in abundance with respect to other piedmont reservoirs (Campbell 1975, Duke Power Company 1976b, Industrial Biotest Laboratories, Inc. 1974, Tackett 1974, Weiss and Kuenzler 1976). Phytoplankton standing crops showed peak abundances in EZC samples at

Locations 500.0 and 506.0 (Figures 4-5 and 4-6) during the summer of each year. Minimum phytoplankton concentrations occurred during winter. This seasonal trend was not as prominent for the near-discharge (508.5) phytoplankton populations (Figure 4-7). The phytoplankton standing crop indices roughly paralleled one another at all three locations after August 1974. Prior to that time, chlorophyll measurements fluctuated differently than cell concentrations (density and biovolume) but generally increased from January to August 1974.

Attempts to determine the causes of seasonal biomass fluctuations have centered on physical, chemical, and biological influences. Physical factors, particularly incident solar radiation and temperature, tend to set the limits of autotrophic growth. Chemical influences, most notably nitrogen and phosphorus, may limit growth within the limits set by light and temperature. The seasonal phytoplankton changes at Locations 500.0 and 506.0 (Figures 4-5 and 4-6) correspond closely to those of solar radiation and surface temperature changes. Thus, during most of the year, the phytoplankton concentrations are probably regulated primarily by physical factors, e.g. solar radiation, water temperature, and vertical mixing.

Secchi disc transparencies remained similar between all three locations, but were generally greatest during the winter-spring period and lowest in the summer-fall period, indicating an inverse relationship to phytoplankton concentrations (Figures 4-5 through 4-7). Transparencies averaged 2.7 m whereas euphotic zone depths averaged 6.5 m (Duke Power Company 1974a, b; 1975a, b; 1976a).

Based on the nitrogen : phosphorus ratios presented in Chapter 3 of this report, the findings of the U. S. Environmental Protection Agency (1975), Lake Keowee can be classified as phosphorus-limited. However, phorphorus and nitrogen concentrations showed little correlation with phytoplankton populations (Chapter 3 and Figures 4-5 through 4-7) with no epilimnetic decrease in these nutrients during stratified periods. These trends in conjunction with low phosphorus concentrations, tend to suggest that during stratified periods when physical factors are not limiting, phorphorus turnover rates probably control phytoplankton growth to a greater extent than the actual nutrient concentrations, as was reported by Fogg (1975).

Location 508.5 phytoplankton exhibited minor temporal fluctuations compared to Locations 500.0 and 506.0 phytoplankton (Figures 4-5 through 4-7). Standing crops were generally lowest at Location 508.5 of the three but showed only slightly higher concentrations to lower depth phytoplankton populations at Location 502.0, to intake and to discharge populations (Figures 4-2 through 4-4). The populations of phytoplankton at Location 508.5 did not appear to respond to elevated temperature or nutrient levels. The travel time of plankton within the discharge area, coupled with vertical mixing probably prevented the discharge area phytoplankton from exhibiting immediate response to elevated temperature or nutrients.

<u>Spatial Variation</u>

Vertical Differences in Phytoplankton

Vertical gradients (EZC minus LSD data) of phytoplankton standing crops at Locations 500.0, 502.0, 506.0 and 508.5 are presented in Figures 4-8 through

4-11. Generally, as the difference between euphotic zone phytoplankton and lower depth populations increased, the vertical thermal gradient (surface temperature minus bottom temperature, C) also increased at Locations 500.0, 502.0, and 506.0. However, maximum vertical plankton differences occurred later than maximum thermal gradients but coincided with maximum surface temperatures and peak euphotic zone standing crops. The mean percent vertical standing crop differences at the skimmer wall were analyzed by stepwise multiple regression. The resulting equation (R^2 = 0.89) is:

Mean Percent Vertical Phytoplankton Difference = 12.0 + 2.6 (Surface Temperature, C) + 4.0 (Vertical Thermal Gradient, C) -0.002 (CCW Flow, m^3/min) + 0.005 (Jocassee Generating Flow, m^3/min) - 0.011 (Jocassee Pumping Flow, m^3/min).

The regression equation ($p \leq 0.1$) indicated that meteorological conditions, ONS flows and Jocassee flows all affected the vertical distribution of phytoplankton at the skimmer wall. The relatively uniform vertical differences at Location 508.5 were attributed to the release of deep water phytoplankton at the ONS discharge and subsequent mixing which created more constant standing crop levels. Vertical temperature gradients at Location 508.5 were lower in the summers of 1975 and 1976 than in 1974, probably due to the higher ONS flows and resultant turbulence in the later years. The thermal gradient at Location 502.0 was generally lower than at Locations 500.0 and 506.0. This was attributed to the depletion of cooler deep water by ONS and induced vertical mixing (Chapter 2). However, the vertical standing crop differences during summer at Location 502.0 were similar to summer standing crops differences at Location 506.0. The euphotic zone phytoplankton fluctuated more than lower depth standing crops which remained similar, spatially and temporally.

Location Differences in Standing Crops

Euphotic zone standing crops indices generally showed a trend of highest phytoplankton concentrations at locations distant from the ONS discharge and lowest concentrations in the discharge area (Figures 4-12 through 4-17). The lower depth samples showed minor spatial variation of standing crops and are not discussed. The horizontal differences in euphotic zone phytoplankton of Lake Keowee were generally more pronounced during the warm months than in cool months. Vertical differences in phytoplankton standing crops followed a similar seasonal pattern. The peak standing crops (September) at Location 500.0 were associated with the presence of elevated nutrient levels. During most other months, EZC standing crops at Location 506.0 were similar in magnitude to those at Location 500.0. The relatively low intake standing crops (Figure 4-3) appeared to have influenced the discharge area standing crops to a great extent during the warm months. At Marshall Steam Station, Lake Norman, NC, Menhinick and Jensen (1974) observed a similar occurrence of lower phytoplankton standing crops in the CCW intake than in reservoir surface waters because of surface skimmer wall exclusion during warm months when maximum vertical phytoplankton differences occurred. Symons et al. (1967) also reported reductions of algal standing crops in Boltz Lake, KY, in areas where bottom waters were artificially mixed with surface waters. When vertical standing crop differences were lowest during cool months, euphotic zone phytoplankton were more uniformly distributed among locations in Lake Keowee.

A cluster analysis procedure (Barr et al. 1976) was performed on data from each of the three phytoplankton standing crop indices. Results indicated that for the period 1974-1976, chlorophyll showed the strongest spatial (location) groupings as: (1) EZC data for Locations 500.0, 502.0, 505.0, and 506.0; and (2) EZC data from Locations 503.0, 508.0, 508.5 and 509.5, The first group was designated the reference-area group and the second as the discharge-area group. The discharge area group represented approximately 10% of the area of Lake Keowee. The intake location (509.5) was included in the analysis since no significant difference was observed between the intake and discharge locations (Entrainment Study).

Results of the cluster analysis were used to form replicate data in a three-factor ANOVA testing differences between lake areas, months, and years (Table 4-5). The three-factor interaction term was non-significant for each standing crop index. The area-year interaction term was significant only for the bio-volume index, indicating yearly taxonomic composition differences. Figure 4-18 illustrates the yearly mean and 95% confidence level for each area (reference and discharge) and each standing crop index. The discharge area had consistently lower concentrations of every standing crop index. However, yearly differences within areas showed little change. Even though the means between years fluctuated slightly, they were within the 95% confidence intervals of each year. No consistent fluctuation of the three standing crop means was observed. These data showed that yearly changes within areas probably did not occur, indicating that phytoplankton distribution within Lake Keowee has stabilized.

The month-year interaction was investigated by a simple main effects test; Table 4-6 shows which months are significantly different between years for each standing crop index. Only November had no significant difference between years for all standing crop indices. However, not one month showed significant differences for all three indices. The results of a least significance difference test (Table 4-7) also indicates the lack of consistency between standing crop means of different years. Of the three indices, density exhibited the most consistent pattern for each of the three years, only July 1976 density being significantly different from 1974 and 1975. However, this difference, in comparison with other North Carolina Lakes (Weiss and Kuenzler 1976), was relatively small and well within natural seasonal variation. Biovolume and chlorophyll as indicators of phytoplankton standing crop are also a function of taxonomic composition and physiological responses. Therefore, the month-year interaction can be explained by the natural seasonal variability of phyto-plankton because all three indices showed inconsistency with respect to monthly-yearly differences.

Since the area-month interaction term (Table 4-5) was significant for all standing crop measurements, a simple main effects analysis (Table 4-8) resulted in non-significant differences during the winter months (January, February, November, and December). However, July and September data showed significant spatial differences for all three phytoplankton indices. The degree of variation among areas during different months was attributed partially to skimmer wall exclusion of euphotic zone phytoplankton which were shown to vary seasonally with respect to vertical differences in phytoplankton. The primary impact on receiving water phytoplankton of CCW use has been to reduce standing crops in the discharge area by mixing deep (aphotic) water with euphotic waters. This was a seasonally dependent phenomenon being less pronounced during cooler months (Figure 4-19). The euphotic zone standing crops showed gradually higher levels with distance from the discharge. The rate of increase of phytoplankton from the discharge was greater in the Little River arm than the Keowee River arm (Figures 4-12 through 4-17). The results correspond with observations from plume mapping studies (Chapter 2) and zooplankton distribution studies of the reservoir (Chapter 6).

The percent reduction in the discharge area relative to the reference area was calculated (Table 4-9) for the months when phytoplankton populations were significantly lower in the discharge area than the reference area (Table 4-8). Generally, the percent reduction increased as the degree of thermal stratification increased. The maximum recorded percent reduction for all three parameters occurred in September. The values presented in Table 4-9 represented maximum reductions in the open lake areas and probably less than 10% of the total surface area of the lake was affected. However, as was previously noted, the absolute amount of phytoplankton and the relative seasonal fluctuations in biomass decreased as the distance from ONS discharge decreased.

As was discussed above, the primary effect of ONS upon Lake Keowee phytoplankton was to pump aphotic zone populations to the surface receiving waters thereby diluting the plankton. Also, the pumping activity changed the vertical mixing regime of the lake contributing to the reduction of surface water plankton. In an attempt to quantify this action, with respect to season and area of the lake, a stepwise multiple regression analysis was used to construct an empirical model to define this reduction based upon the operation of ONS and Jocassee Pumped Storage Station. The dependent variable was defined as the Mean Percent Phytoplankton Reduction [equation (1) and (2), Table 4-10]. This value was relative to Location 500.0 since the highest phytoplankton populations were generally observed at 500.0 and the percent reduction would therefore represent the maximum reduction effect. The independent variables tested included the distance (km) from the discharge point, the surface temperature (C) at Location 502.0, the vertical thermal gradient (surface temperature minus bottom temperature, C) at Location 502.0, the weekly mean CCW flow (prior to sampling) through ONS (m^3/min), and the generating and pumping flow rates (m^3/min) through the Jocassee Station. The data were tested for each arm (Little River, Keowee River) in Lake Keowee. The resultant regression models are as follows:

Little River: Mean Percent Phytoplankton Reduction =

21.0 - 4.1 (Distance) - 2.0 (Vertical Thermal Gradient)
+ 3.0 (Surface Temperature) -0.004 (CCW Flow)
+ 0.001 (Jocassee Pumping Flow) $R^2 = 0.65$

Keowee River: Mean Percent Phytoplankton Reduction =

9.3 - 4.2 (Distance) - 3.5 (Vertical Thermal Gradient)
+ 4.3 (Surface Temperature) - 0.0054 (CCW Flow)
+ 0.0019 (Jocassee Pumping Flow) $R^2 = 0.60$

The selected variables accounted for approximately 65% and 60%, respectively, of the variability of the percent reduction in the Little River arm and Keowee River arm.

Determination of the mean monthly values of the significant independent variables permitted the regression model to estimate monthly mean percent reduction at two kilometer intervals (from the discharge structure) throughout the lake. These mean percent reduction estimates were used to estimate the monthly weighted total percent phytoplankton reduction in Lake Keowee [equation (3), Table 4-10]. The same procedure was used to determine monthly weighted total percent phytoplankton reduction of the observed data by assuming lake sampling locations represented a respective lake surface area. The results of the analyses (Figure 4-20) show that the empirically predicted values typically overestimated the actual observed weighted phytoplankton reduction but usually fell within the 95% confidence interval of the observed monthly mean reduction. The minimum effect of ONS and Jocassee Station was observed during the winter months. As the lake became thermally stratified, the lake-wide reduction in phytoplankton also increased until the maximum mean reduction was observed in September. However, the 95% confidence intervals indicated a wide range (maximum: $-9<\bar{x}<62$) of statistically probable phytoplankton reductions. The high variability of the data indicated a highly complicated system, i.e. with natural seasonal phenomena occurring, heated deep water discharged to the surface, water movement into and out of Lake Keowee via Jocassee Station, and water movement of different directions and magnitude under different operating conditions.

Potential increased phytoplankton production (arising from increased heat and nutrient levels), which was not observed during the short-term entrainment studies, was also not reflected in increased standing crops of phytoplankton nor zooplankton (Chapter 6). This discharge area reduction in both planktonic trophic levels indicates a loss of autochthonous production within the reservoir. However, since Location 500.0 was used as the reference point and cove phytoplankton data were excluded from the analysis, the data presented in Figure 4-20 probably represent an overestimate of the total reduction within the reservoir. Even though overestimates of reduction were intentionally determined, the data in Figure 4-20, coupled with the trend of decreasing phosphorus concentrations (Chapter 3), and stabilized year to year standing crop means (Figure 4-18), indicate the combined effects of the generating facilities on Lake Keowee are at least maintaining the trophic status of the lake, or are at most, gradually causing a tendency toward more oligotrophic conditions.

SUMMARY AND CONCLUSIONS

1. Chlorophyceae (green algae) usually dominated the phytoplankton densities during the summer and early fall whereas diatoms were winter and spring dominants. Diatoms and dinoflagellates usually comprised the majority of the phytoplankton biovolume. Blue-green algae were rarely as abundant as diatoms, green algae and dinoflagellates. Major changes in phytoplankton composition were not evident during the monitoring period, 1974-1976.

2. Phytoplankton entrainment studies showed minimal, if any, immediate effects of ONS condenser passage on the indices density, biovolume and chlorophyll.

All three indices showed similar seasonal trends with greater phytoplankton concentrations entering the CCW system during the summer than during winter. Statistical analyses of carbon assimilation ratios between intake and discharge water indicated that thermal, mechanical and total CCW passage effects did not significantly alter primary productivity of entrained organisms.

3. The phytoplankton of Lake Keowee were sparse in abundance as compared to other piedmont reservoirs. Surface water phytoplankton had higher abundances during the thermally stratified period than during isothermal conditions. The seasonal abundance of phytoplankton is generally controlled by solar radiation, temperature, and mixing regimes, whereas phosphorus turnover rates probably regulate the maximum achievable summer standing crops.

4. Although prior predictions listed thermal shock as the most significant impact on reservoir phytoplankton (U. S. Atomic Energy Commission 1972), data indicated that phytoplankton abundance in the discharge area was altered primarily by dilution with deep water which contained lower standing crops than surface waters. The magnitude of this dilution showed seasonal variation, being greater during months when vertical standing crop differences were greatest. Thus, an area proximate to the ONS discharge, representing an area not greater than 10% of the reservoir, sometimes exhibited significantly lower euphotic zone phytoplankton abundances than reference areas. When significant, the percent difference of standing crops between areas ranged from 48 to 79%. The exclusion of surface water phytoplankton by the intake skimmer wall evidently controls the ONS discharge area phytoplankton abundance to a greater extent than any effects of thermal inputs by ONS. However, thermal discharges, coupled with deep water withdrawal, tend to enhance deeper vertical mixing, thereby diluting the surface phytoplankton further.

5. The phytoplankton dilution effect from Oconee Nuclear Station follows the thermal plume; hence, the Keowee River arm was affected more than the Little River arm.

6. Lake-wide area weighted phytoplankton reduction was estimated by the use of a stepwise regression procedure. Using the vertical temperature gradient and surface temperature lake-side of the skimmer wall, ONS pumping rates, and Jocassee pumping rates, the resulting empirical model accounted for approximately 60-65% of the observed variability of phytoplankton reduction. The model, however, typically overestimated the reduction based on area weighted observed values. Observed lake-wide phytoplankton reduction estimates ranged from -3 (indicating an enhancement of standing crops) to 36% reduction.

7. The impact on euphotic zone phytoplankton caused by the generating facilities on Lake Keowee appears to have stabilized since Oconee Nuclear Station began operation in 1973.

RECOMMENDATIONS

1. Monitoring of phytoplankton in the CCW system at ONS should be discontinued because no significant spatial variations of standing crops and primary productivity were observed for the three years of summarized data. No noticeable alteration was observed even though ONS operated at a high capacity in 1975. Therefore, the phytoplankton monitoring portion of Technical Specification 1.5 for ONS (Duke Power Company 1973) should be discontinued.

2. Receiving water phytoplankton populations showed lower standing crop levels in the vicinity of the ONS discharge than at reference areas of the reservoir. Since monitoring of phytoplankton began, spatial and temporal variations in surface water phytoplankton have stabilized into a predictable pattern. Thus, it is recommended that the receiving water phytoplankton monitoring portion of Technical Specification 1.3.4 for ONS (Duke Power Company 1973) be discontinued.

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Table 4-1

Lake Keowee and Oconee Nuclear Station phytoplankton sampling locations and frequency.

Sampling Month	Location 500.0	502.0	503.0	505.0	506.0	508.0	508.5	509.5	530.0	530.3	530.6	530.9
July 1973	P,C		P,C*	P,C*	P,C	P,C*		P,C*	P*			P*
September 1973	P,C		P,C*	P,C*	P,C	P,C*		P,C*	P,C,CU*	P,C,CU*	P,C,CU*	P,C,CU*
November 1973	P,C		P,C*	P,C*	P,C	P,C*		P,C*	P,C,CU*	P,C,CU*	P,C,CU*	P,C,CU*
January 1974	P,C		P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
March 1974	P,C,	P,C	P,C,	P,C,	P,C,	P,C,	P,C,	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
May 1974	P,C	P,C,	P,C,	P,C,	P,C	P,C	P,C	P,C				
June 1974									P,C,CU	P,C,CU	P,C,CU	P,C,CU
July 1974	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
August 1974	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C				
September 1974	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
October 1974	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C				
November 1974	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C				
December 1974	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
January 1975	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C				
February 1975	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
March 1975	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
April 1975	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C				
May 1975	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
June 1975	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C				
July 1975	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU			P,C,CU
September 1975	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
October 1975									P,C,CU	P,C,CU	P,C,CU	P,C,CU
November 1975	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
January 1976	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
March 1976	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
May 1976	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
July 1976	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
September 1976	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU	P,C,CU	P,C,CU	P,C,CU
November 1976	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C	P,C,CU		P,C,CU	P,C,CU

P - A population sample was collected.
C - A chlorophyll sample was collected.
CU- A carbon uptake study was performed.
* - Data was not discussed in text.

Table 4-2

Mean phytoplankton density ($X10^6$ units/m^3), biovolume (mm^3/m^3), and total chlorophyll (mg/m^3) for ONS entrainment studies.

LOCATION	1974 1/22	1974 3/20	1974 6/13	1974 7/16	1974 9/11	1974 12/11	1975 2/12	1975 3/13	1975 5/21	1975 7/16	1975 9/16	1975 10/14	1975 11/12	1976 1/14	1976 3/17	1976 5/11	1976 7/8	1976 9/15	1976 11/10	1974 Year Means	1975 Year Means	1976 Year Means
Density																						
530.0	88	163	282	124	240	166	230	140	228	95	349	236	109	216	122	94	351	253	328	177	198	227
530.3	104	134	300	140	288	186	178	172	205		362	152	99	284	178	157	489	301		192	195	282
530.6	125	194	342	148	146	165	364	176	134		342	246	80	242	133	129	506	293	255	187	224	260
530.9	121	251	301	246	226	208	231	132	312	101	286	142	100	177	190	154	376	349	178	226	186	237
Mean	110	186	306	164	225	181	251	155	220	98	335	194	97	230	156	134	430	299	254			
Biovolume																						
530.0	293	55	74	58	160	132	106	96	82	70	352	76	100	190	95	50	101	78	225	129	126	123
530.3	43	46	92	70	96	102	98	116	78		369	74	84	229	115	98	176	195		75	136	163
530.6	49	54	126	48	38	130	174	244	62		288	82	104	184	105	68	112	174	190	74	159	139
530.9	61	59	184	82	89	158	132	118	158	86	298	60	80	112	70	76	99	153	124	106	133	106
Mean	112	54	119	64	96	130	128	144	95	78	327	73	92	179	96	73	122	150	180			
Total Chlorophyll																						
530.0	0.51	0.48	0.82	0.53	0.44	0.52	0.70	1.06	0.73	0.74	2.09	0.88	0.67	1.23	1.46	0.96	0.64	1.10	0.60	0.55	0.98	1.00
530.3	0.63	0.53	0.65	0.60	0.60	0.46	0.78	1.01	0.88		1.82	0.80	0.82	1.20	1.01	0.49	0.74	1.20		0.58	1.02	0.93
530.6	0.65	0.56	0.70	0.49	0.64	0.46	0.82	1.01	0.78		2.05	0.78	0.70	1.06	1.01	0.93	0.54	1.55	0.84	0.58	1.02	0.99
530.9	0.53	0.47	0.82	0.54	0.62	0.39	0.60	0.96	1.10	0.98	1.96	0.86	0.74	0.82	1.36	1.02	0.80	1.16	0.64	0.56	1.03	0.97
Mean	0.58	0.51	0.75	0.54	0.58	0.46	0.72	1.01	0.87	0.86	1.98	0.83	0.73	1.08	1.21	0.85	0.68	1.25	0.69			

530.0 - intake location
530.3 - precondenser location
530.6 - postcondenser location
530.9 - discharge location

Table 4-3

Two-factor analysis of variance of total chlorophyll and analysis of simple main effects for four entrainment locations at ONS, 1974-1976.

Source	Degrees of Freedom (df)	Sum of Squares (SS)	Mean Square (MS)	F-Ratio (F)	Probability
Chlorophyll among locations	3	0.03	0.01	0.47	$p>0.50$
Chlorophyll among dates	18	18.02	1.00	49.97*	$p<0.05$
Location X Date	51	1.86	0.04	1.75	$p>0.05$
Error	75	1.56	0.02		

Analysis of simple main effects of chlorophyll for 18 dates

Source	(df)	(SS)	(MS)	(F)	Probability
January 1974	3	0.03	0.01	0.47	$p>0.50$
March 1974	3	0.01	0.00	0.18	$p>0.75$
June 1974	3	0.04	0.01	0.70	$p>0.50$
July 1974	3	0.01	0.00	0.22	$p>0.75$
September 1974	3	0.05	0.02	0.76	$p>0.50$
December 1974	3	0.02	0.01	0.25	$p>0.75$
February 1975	3	0.06	0.02	0.93	$p>0.25$
March 1975	3	0.01	0.00	0.14	$p>0.75$
May 1975	3	0.16	0.05	2.58	$p>0.05$
September 1975	3	0.08	0.03	1.32	$p>0.25$
October 1975	3	0.01	0.00	0.21	$p>0.75$
November 1975	3	0.03	0.01	0.43	$p>0.50$
January 1976	3	0.22	0.07	3.43*	$p<0.05$
March 1976	3	0.33	0.11	5.30*	$p<0.05$
May 1976	3	0.03	0.01	0.50	$p>0.50$
July 1976	3	0.07	0.02	1.18	$p>0.25$
September 1976	3	0.25	0.08	4.03*	$p<0.05$
November 1976	3	0.10	0.03	1.59	$p>0.10$

* significant at the $\alpha = 0.05$ level

Table 4-4

Mean carbon assimilation ratios (mg carbon/mg chlorophyll/hr) and mean incubation temperatures (MIT) for assessment of phytoplankton entrainment effects at ONS.

	Entrainment Location					
	530.0		530.0		530.9	
Sampling Date	Assimilation Ratio	MIT,C	Assimilation Ratio	MIT,C	Assimilation Ratio	MIT,C
1/22/74	0.86	12.0	0.98	16.0	0.66	16.0
3/20/74	1.35	12.0	1.68	15.0	1.22	15.0
6/13/74	0.57	18.5	0.81	23.0	0.58	23.0
7/16/74	0.58	19.0	0.44	29.0	1.02	29.0
9/11/74	*	*	0.69	28.0	0.56	28.0
12/11/74	1.96	12.5	1.77	19.0	1.90	19.0
2/12/75	1.64	11.5	2.23	16.5	4.19	16.5
3/13/75	1.42	11.0	1.21	18.0	1.27	18.0
5/21/75	1.22	17.5	1.08	23.0	1.59	23.0
7/16/75	4.98	21.5	4.12	29.0	4.60	29.0
9/16/75	1.01	24.0	1.31	32.0	1.03	32.0
10/14/75	1.54	23.5	1.53	29.5	0.97	29.5
11/12/75	1.53	20.0	1.39	26.0	0.90	26.0
1/14/76	0.86	11.0	0.78	21.0	1.06	21.0
3/17/76	1.13	11.5	1.12	19.0	1.65	19.0
5/11/76	1.50	14.5	1.48	21.5	1.83	21.5
7/8/76	0.52	17.5	0.57	27.0	0.57	27.0
9/15/76	1.09	24.0	0.63	30.5	1.64	30.5
11/10/76	4.40	17.5	4.24	23.0	3.38	23.0

530.0 - intake location
530.9 - discharge location
* - carbon uptake for dark bottle exceeded light bottle carbon uptake

Table 4-5

Three-factor analysis of variance for Lake Keowee EZC phytoplankton standing crop indices, 1974-1976.

Source	df	SS	MS	F	Probability
(1) **Density**					
reference to discharge areas (A)	1	2.46×10^6	2.46×10^6	26.36*	$P<0.05$
A among months (M)	11	5.25×10^6	4.77×10^5	5.11*	$P<0.05$
A among years (Y)	2	3.60×10^5	1.80×10^5	1.93	$P>0.10$
A x M	11	2.89×10^6	2.63×10^5	2.82*	$p<0.05$
A x Y	2	1.29×10^5	6.45×10^4	0.69	$p>0.50$
M x Y	10	2.04×10^6	2.04×10^5	2.19*	$p<0.05$
A x M x Y	10	4.24×10^5	4.24×10^4	0.45	$p>0.90$
Error	143	1.33×10^7	9.33×10^4		
(2) **Biovolume**					
A	1	2.01×10^6	2.01×10^6	55.37*	$p<0.05$
M	11	2.61×10^6	2.37×10^5	6.53*	$p<0.05$
Y	2	9.22×10^5	4.61×10^5	12.70*	$p<0.05$
A x M	11	1.38×10^6	1.25×10^5	3.44*	$p<0.05$
A x Y	2	3.50×10^5	1.75×10^5	4.82*	$p<0.05$
M x Y	10	1.40×10^6	1.40×10^5	3.86*	$p<0.05$
A x M x Y	10	4.07×10^5	4.07×10^4	1.12	$p>0.30$
Error	143	5.19×10^6	3.63×10^4		
(3) **Chlorophyll**					
A	1	38.44	38.44	81.70*	$p<0.05$
M	11	58.03	5.28	11.23*	$p<0.05$
Y	2	0.72	0.36	0.77	$p>0.45$
A x M	11	19.71	1.79	3.81*	$p<0.05$
A x Y	2	1.27	0.64	1.36	$p>0.25$
M x Y	10	14.08	1.41	3.00*	$p<0.05$
A x M x Y	10	4.35	0.44	0.94	$p>0.50$
Error	143	67.43	0.47		

* significant at the $\alpha = 0.05$ level

Table 4-6

Simple main effects of the month-year interaction from the three-factor ANOVA for Lake Keowee phytoplankton standing crop indices, 1974-1976.

	Index								
	Density			Biovolume			Chlorophyll		
Sampling Month	MS*	F	Probability	MS	F	Probability	MS	F	Probability
January	2.44×10^5	2.62	$p>0.05$	1.25×10^5	3.44**	$p<0.05$	1.70	3.62**	$p<0.05$
March	2.48×10^5	2.65	$p>0.05$	5.55×10^5	15.29**	$p<0.05$	0.01	0.02	$p>0.75$
May	1.88×10^5	2.02	$p>0.10$	2.93×10^5	8.07**	$p<0.05$	2.76	5.87**	$p<0.05$
July	4.25×10^5	4.56**	$p<0.05$	5.3×10^5	14.60**	$p<0.05$	0.10	0.22	$P>0.75$
September	1.78×10^5	1.91	$p>0.10$	5.7×10^4	1.57	$p>0.10$	1.82	3.88**	$p<0.05$
November	1.19×10^5	1.28	$p>0.25$	8.5×10^4	2.34	$p>0.10$	0.34	0.73	$p>0.25$
Three-factor ANOVA Error	9.33×10^4			3.63×10^4			0.47		

* Each month MS = month SS/2 df.
** Significant at the $\alpha = 0.05$ level

Table 4-7

Results of the least significant difference tests for the month-year interaction term in Table 4-5 and the simple main effects analysis of Table 4-6 for phytoplankton standing crop indices, 1974-1976

Month/Index	Mean by Year		
1.) January/Biovolume	1974	1975	1976
(least significant difference = 194)	42	152	299
	*		
2.) January/Chlorophyll	1975	1976	1974
(least significant difference = 0.70)	0.73	1.19	1.68
3.) March/Biovolume	1974	1976	1975
(least significant difference = 189)	113	128	288
4.) May/Biovolume	1974	1976	1975
(least significant difference = 189)	131	150	472
5.) May/Chlorophyll	1976	1975	1974
(least significant difference = 0.68)	1.58	2.17	2.75
6.) July/Density	1974	1975	1976
(least significant difference = 302)	365	460	803
7.) July/Biovolume	1974	1975	1976
(least significant difference = 189)	174	397	687
8.) September/Chlorophyll	1974	1976	1975
(least significant difference = 0.68)	1.44	2.06	2.38

* underline indicates that means are not significantly different at $\alpha = 0.05$ level.

Table 4-8

Simple main effects of the area-month interaction from the three-factor ANOVA for Lake Keowee phytoplankton standing crop indicies 1974-1976.

	Index								
	Density			Biovolume			Chlorophyll		
Sampling Month	MS*	F	Probability	MS	F	Probability	MS	F	Probability
January	8.50×10^4	0.91	$p>0.25$	5.53×10^4	1.52	$p>0.10$	1.84	3.91	$p\approx0.05$
February	3.00×10^3	0.03	$p>0.75$	8.91×10^3	0.24	$p>0.50$	0.30	0.64	$p>0.25$
March	1.28×10^4	0.14	$p>0.50$	3.47×10^4	0.96	$p>0.25$	5.34	11.36**	$p<0.05$
April	1.10×10^5	1.18	$p>0.25$	2.01×10^5	5.54**	$p<0.05$	1.05	2.23	$p>0.10$
May	1.40×10^5	1.50	$p>0.10$	1.41×10^5	3.88	$p>0.05$	12.19	25.94**	$p<0.05$
June	1.49×10^5	1.60	$p>0.10$	3.18×10^5	8.76**	$p<0.05$	1.06	2.26	$p>0.10$
July	9.80×10^5	10.50**	$p<0.05$	7.08×10^5	19.50**	$p<0.05$	25.69	54.66**	$p<0.05$
August	5.63×10^4	0.60	$p>0.25$	2.02×10^4	0.56	$p>0.25$	2.88	6.13**	$p<0.05$
September	4.22×10^6	45.23**	$p<0.05$	1.90×10^6	52.34**	$p<0.05$	23.09	49.13**	$p<0.05$
October	1.00×10^5	1.07	$p>0.25$	2.91×10^5	8.02**	$p<0.05$	0.77	1.64	$p>0.10$
November	1.81×10^5	1.94	$p>0.10$	1.16×10^5	3.20	$p>0.05$	1.20	2.55	$p>0.10$
December	7.02×10^3	0.08	$p>0.75$	7.26×10^3	0.20	$p>0.50$	0.02	0.04	$p>0.75$
Three-factor ANOVA Error	9.33×10^4			3.63×10^4			0.47		

* Each month MS = month SS/1 df.
** Significant at the α = 0.05 level.

Table 4-9

Significant monthly differences for euphotic zone phytoplankton standing crops between reference and discharge areas of Lake Keowee, averaged for 1974-1976 (mean ± 95% confidence interval).

Index	Month	n	Reference Area	Discharge Area	Percent Reduction Relative to Reference Mean
Density	July	12	745 ± 196	340 ± 141	54
	September	12	1211 ± 607	372 ± 128	68
Biovolume	April	4	648 ± 448	331 ± 194	49
	June	4	748 ± 493	349 ± 372	53
	July	12	591 ± 244	248 ± 139	58
	September	12	715 ± 310	152 ± 48	79
	October	4	595 ± 375	214 ± 57	64
Chlorophyll	March	12	1.93 ± 0.22	0.99 ± 0.24	49
	May	12	2.88 ± 0.55	1.45 ± 0.64	50
	July	12	3.28 ± 0.66	1.21 ± 0.35	63
	August	4	2.50 ± 2.19	1.30 ± 1.49	48
	September	12	2.94 ± 0.95	0.98 ± 0.24	67

Table 4-10

Equations used to calculate the weighted total percent phytoplankton reduction in Lake Keowee, SC, 1974-1976.

(1) $$\text{Percent Reduction}_{tx} = \left[\frac{EZC_{500} - EZC_{x}}{EZC_{500}}\right]_{tx} 100$$

where; EZC_{500} = Euphotic Zone Concentration of chlorophyll, density, or biovolume at Location 500

EZC_{x} = Euphotic Zone Concentration of chlorophyll, density, or biovolume at any other Location

tx = Sample date at a given Location

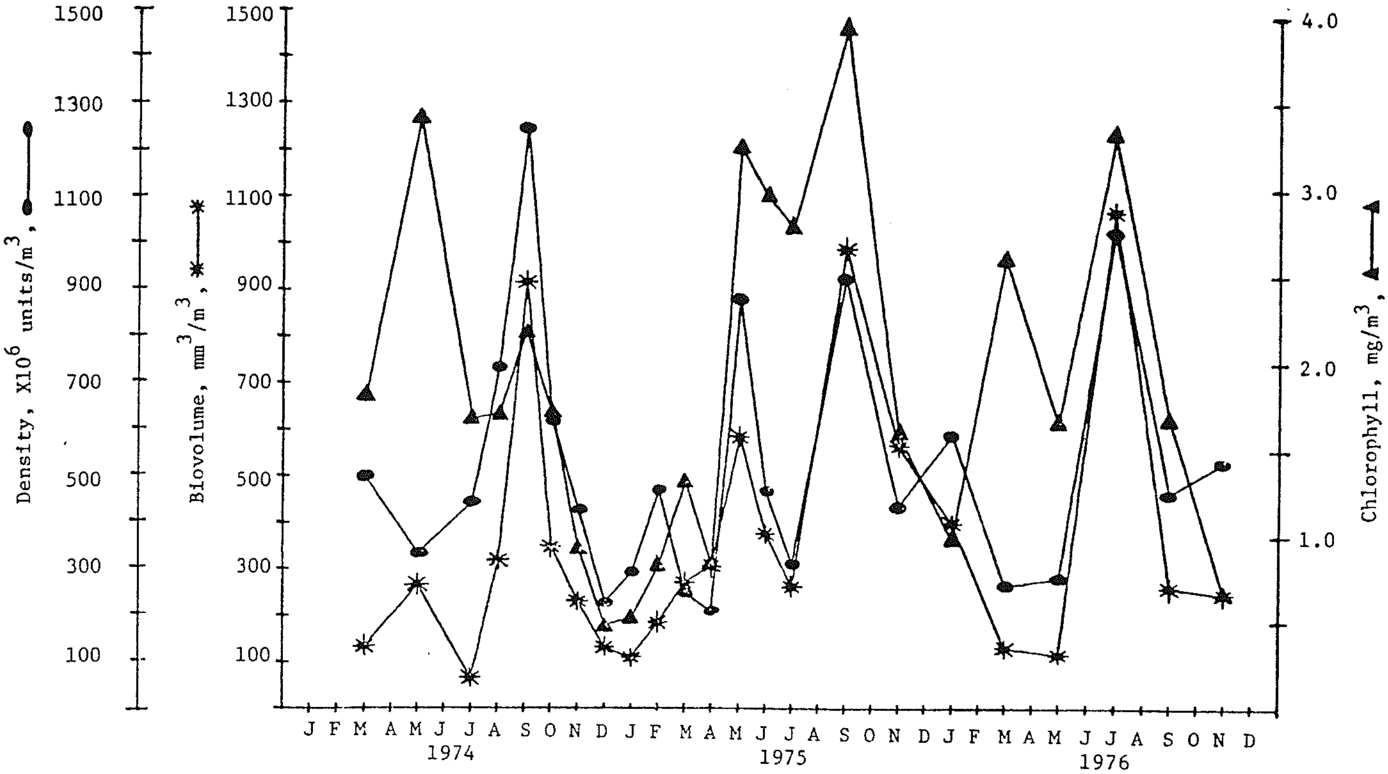
(2) $$\text{Mean Percent Phytoplankton Reduction}_{tx} = \left[\underset{\text{(Chlorophyll)}}{\%\ \text{Reduction}_{tx}} + \underset{\text{(Density)}}{\%\ \text{Reduction}_{tx}} + \underset{\text{(Biovolume)}}{\%\ \text{Reduction}_{tx}}\right]$$

(3) $$\text{Monthly Weighted Total Percent Phytoplankton Reduction} = f_1\left(\frac{\widetilde{\%\ RED}_{d} + \widetilde{\%\ RED}_{d+2}}{2}\right) + f_2\left(\frac{\widetilde{\%\ RED}_{d+2} + \widetilde{\%\ RED}_{d+4}}{2}\right) + \cdot\ \cdot\ \cdot\ f_n\left(\frac{\widetilde{\%RED}_{d+i} + \widetilde{\%RED}_{d+i+2}}{2}\right)$$

where; f_n = fraction of Lake Keowee Surface Area Between d+i and d+i+2

$\widetilde{\%\ RED}_{d+i}$ = Regression estimate of $_{d+i}$ Percent Phytoplankton Reduction

d = distance in kilometers from discharge structure



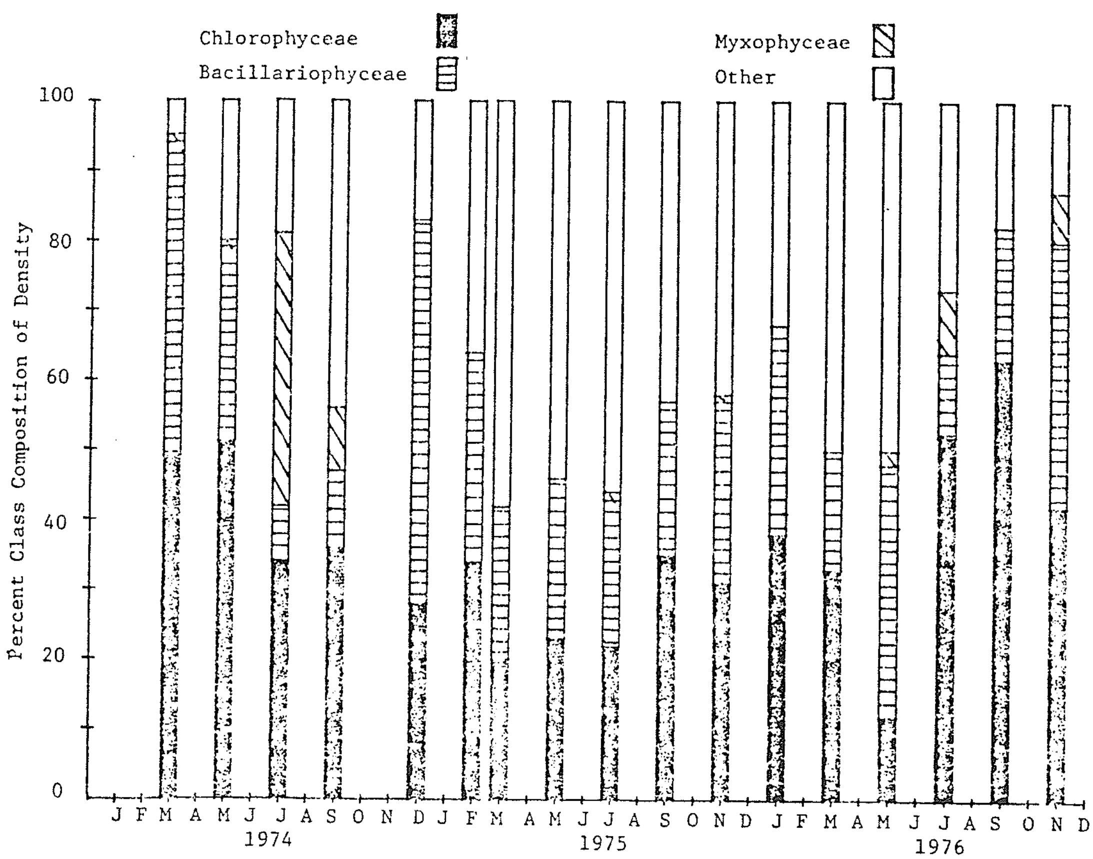


Figure 4-1. Location 502.0 phytoplankton standing crop indices and density percent class composition for euphotic zone composite (EZC).

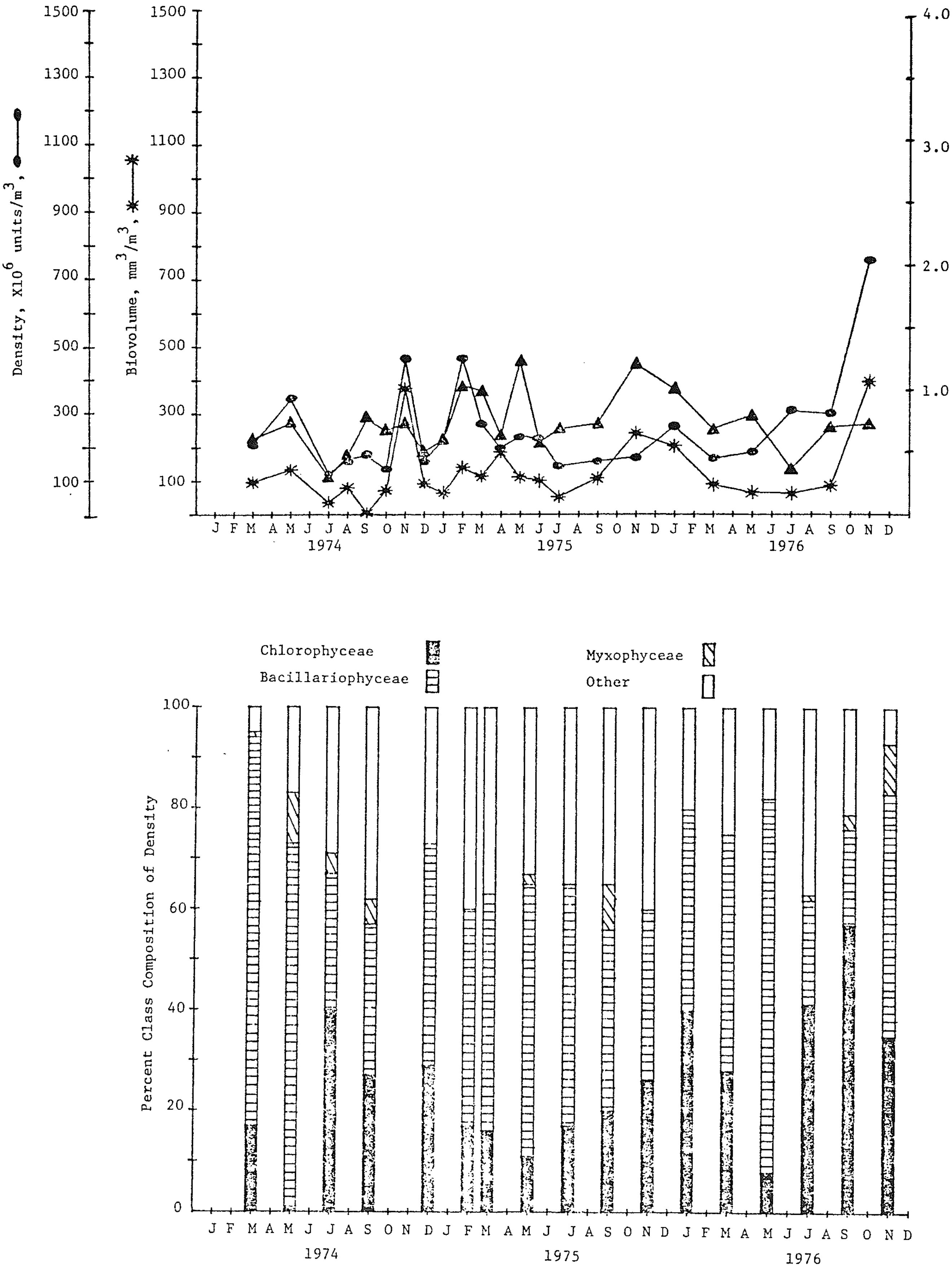


Figure 4-2. Location 502.0 phytoplankton standing crop indices and density percent class composition for lower depth samples (LSD).

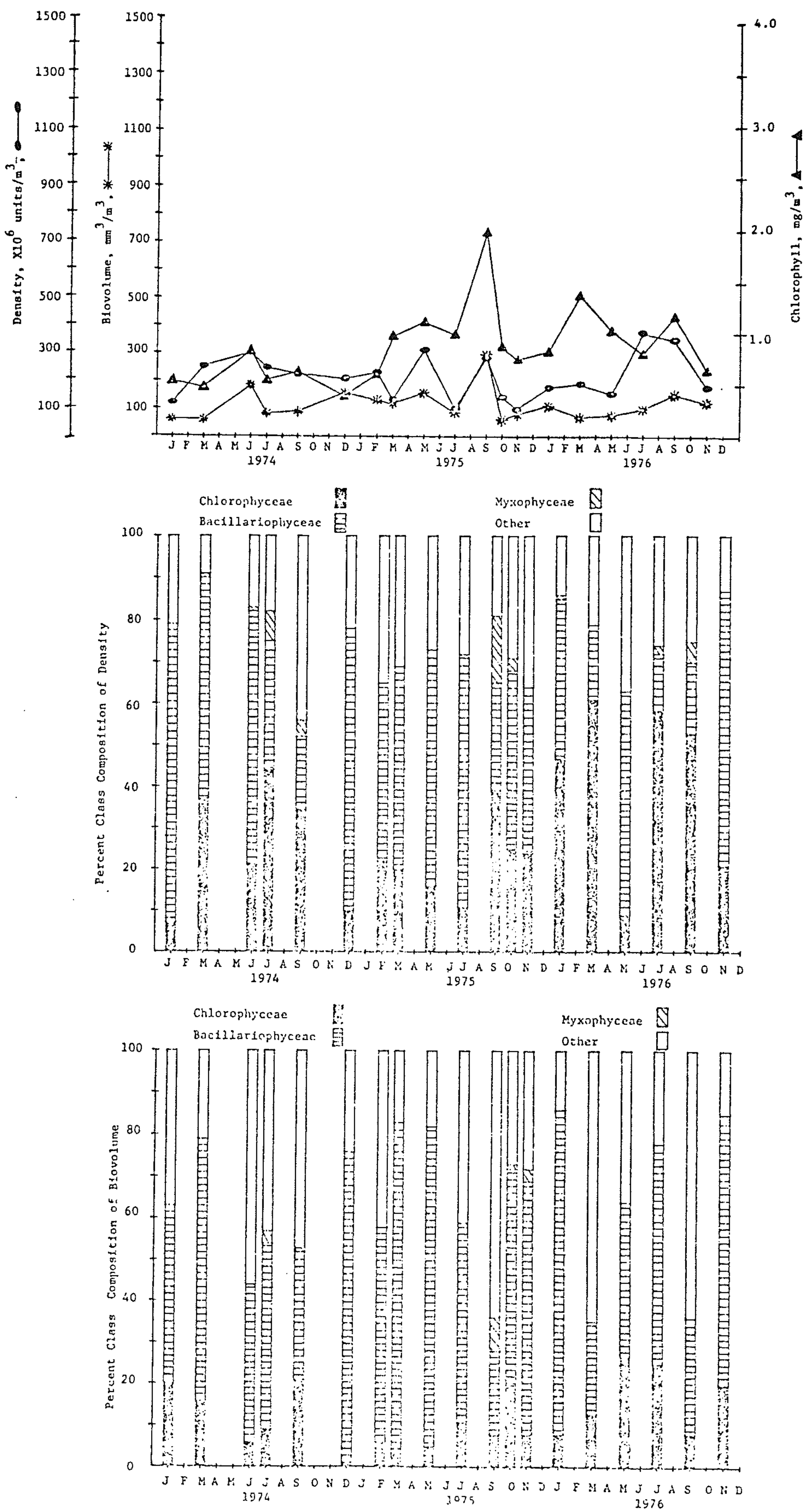


Figure 4-3. Intake location (530.0) phytoplankton standing crop indices, density percent class composition, and biovolume percent class composition.

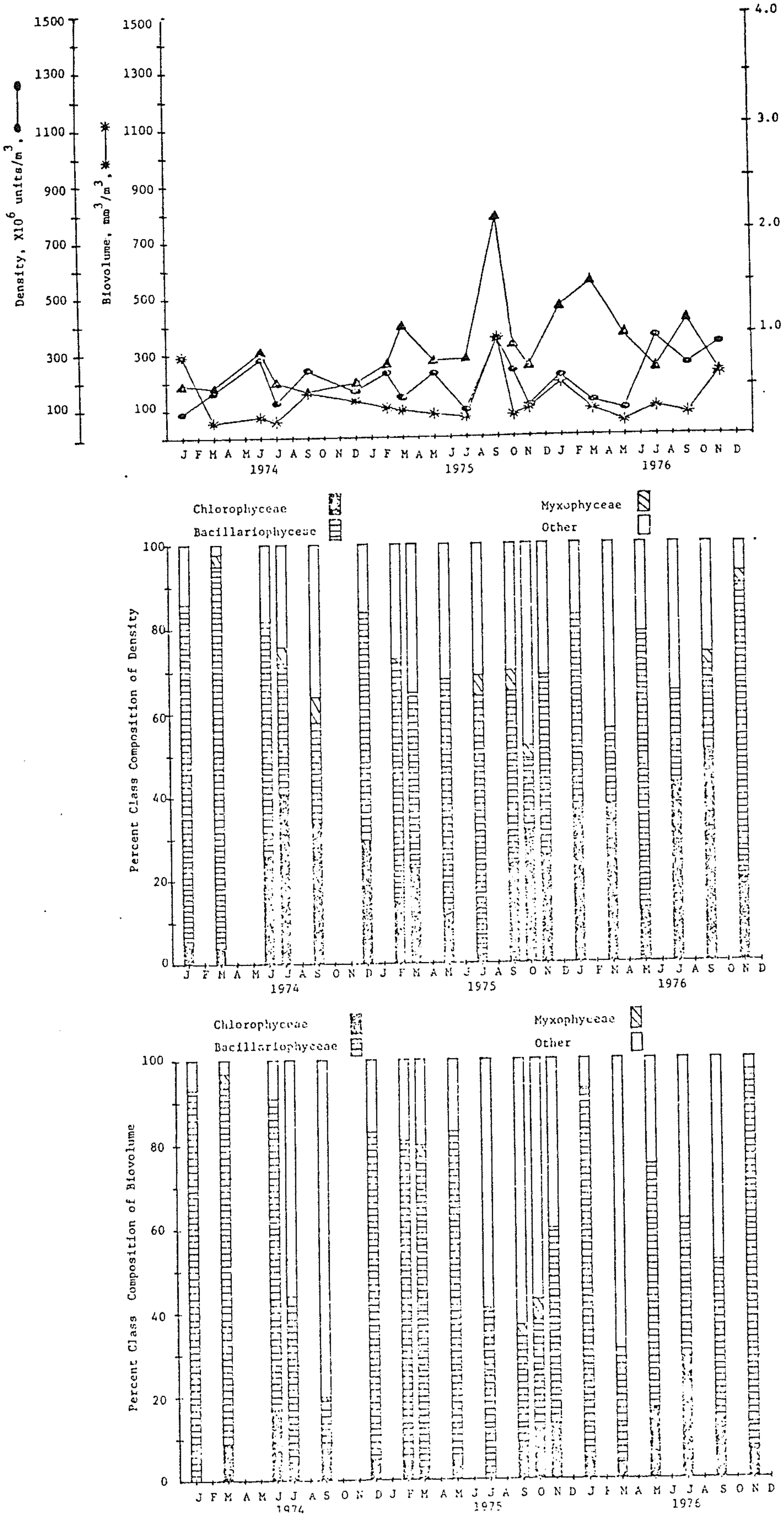


Figure 4-4. Discharge location (530.9) phytoplankton standing crop indices, density percent class composition, and biovolume percent class composition.

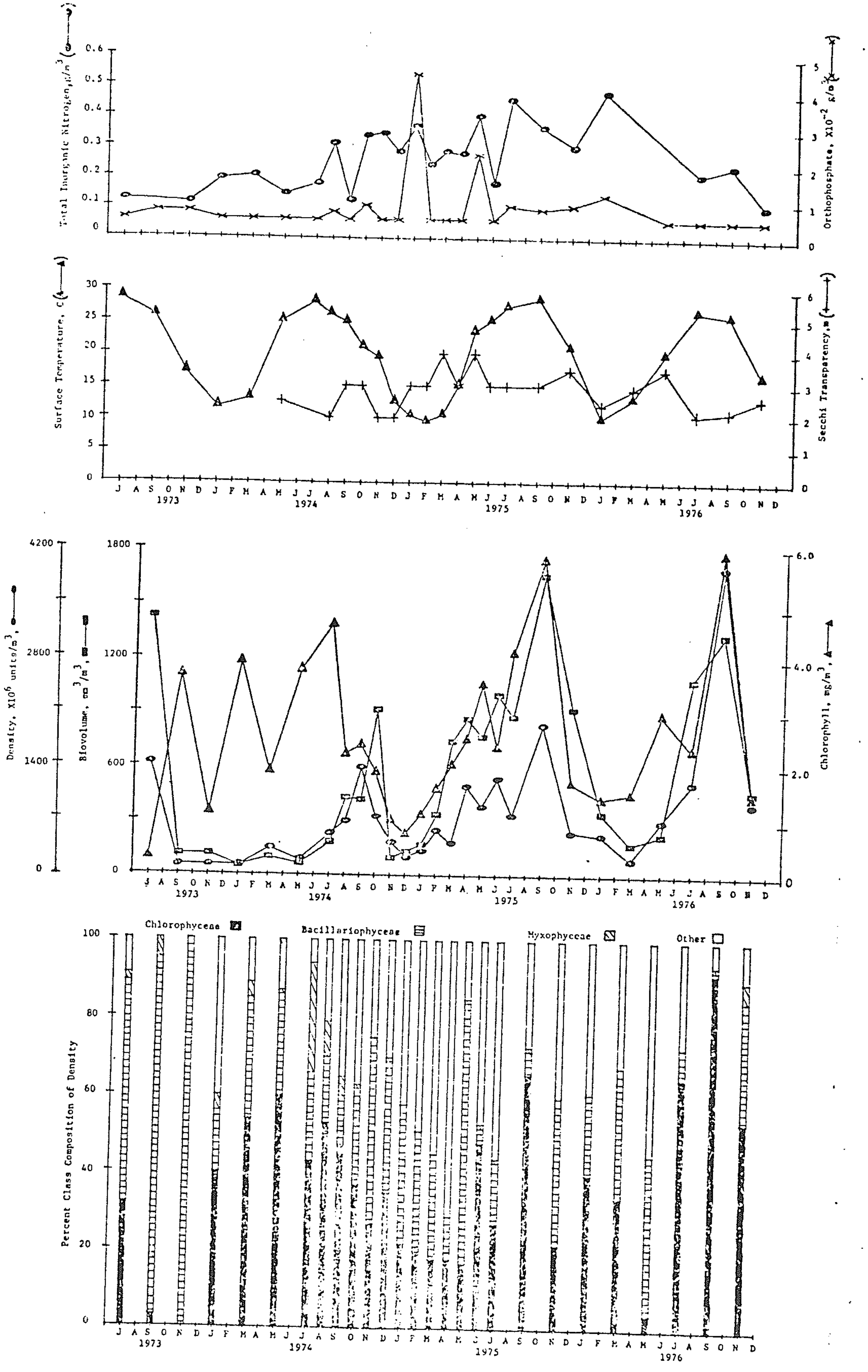


Figure 4-5. Temporal variation of physical-chemical variables associated with mean euphotic zone (EZC) phytoplankton indices for Location 500.0, Lake Keowee, SC (total inorganic nitrogen and orthophosphate are averages of three observations between 0.3 and 10m).

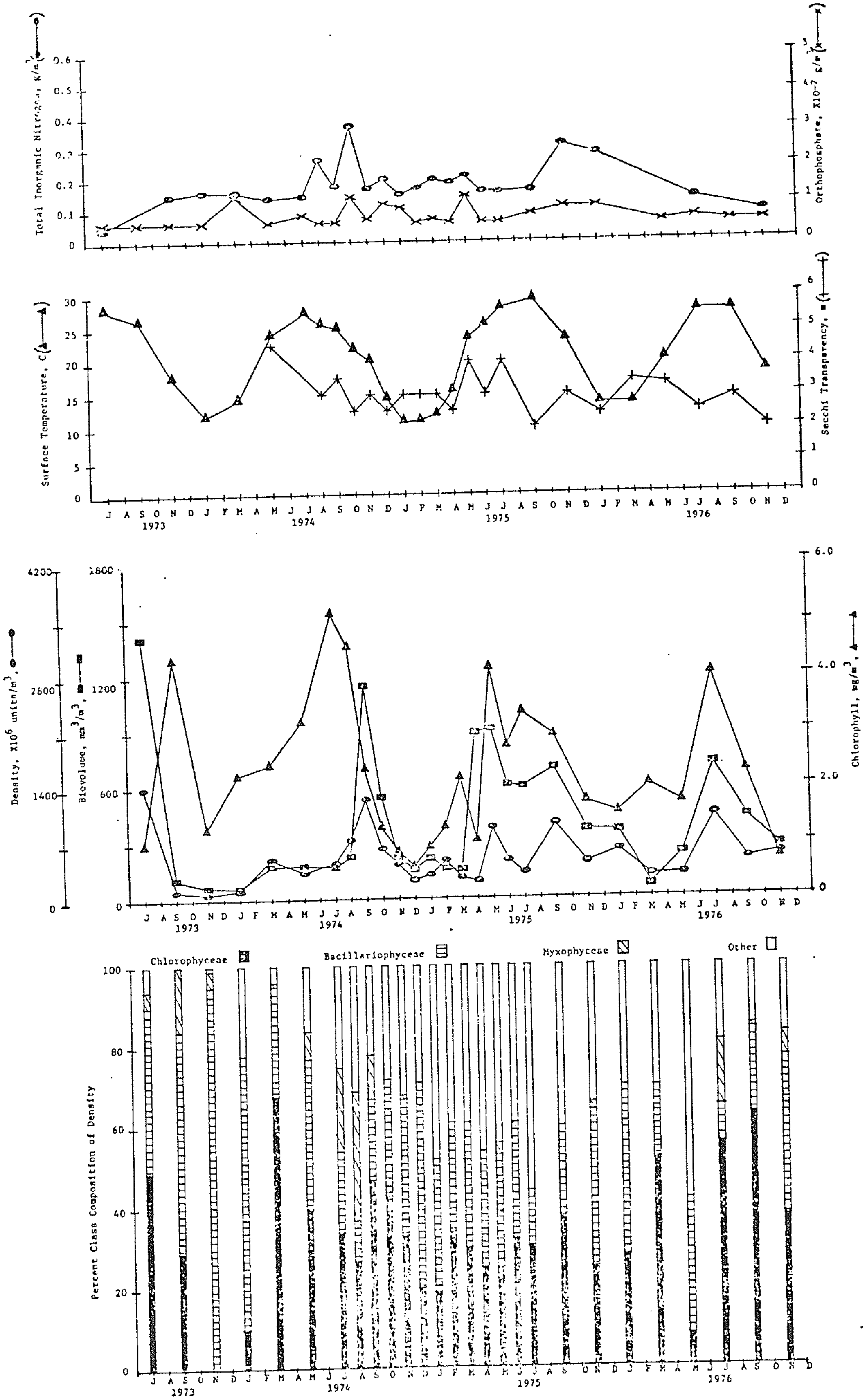


Figure 4-6. Temporal variation of physical-chemical variables associated with mean euphotic zone (EZC) phytoplankton indices for Location 506.0, Lake Keowee, SC (total inorganic nitrogen and orthophosphate are averages of three observations between 0.3 and 10m).

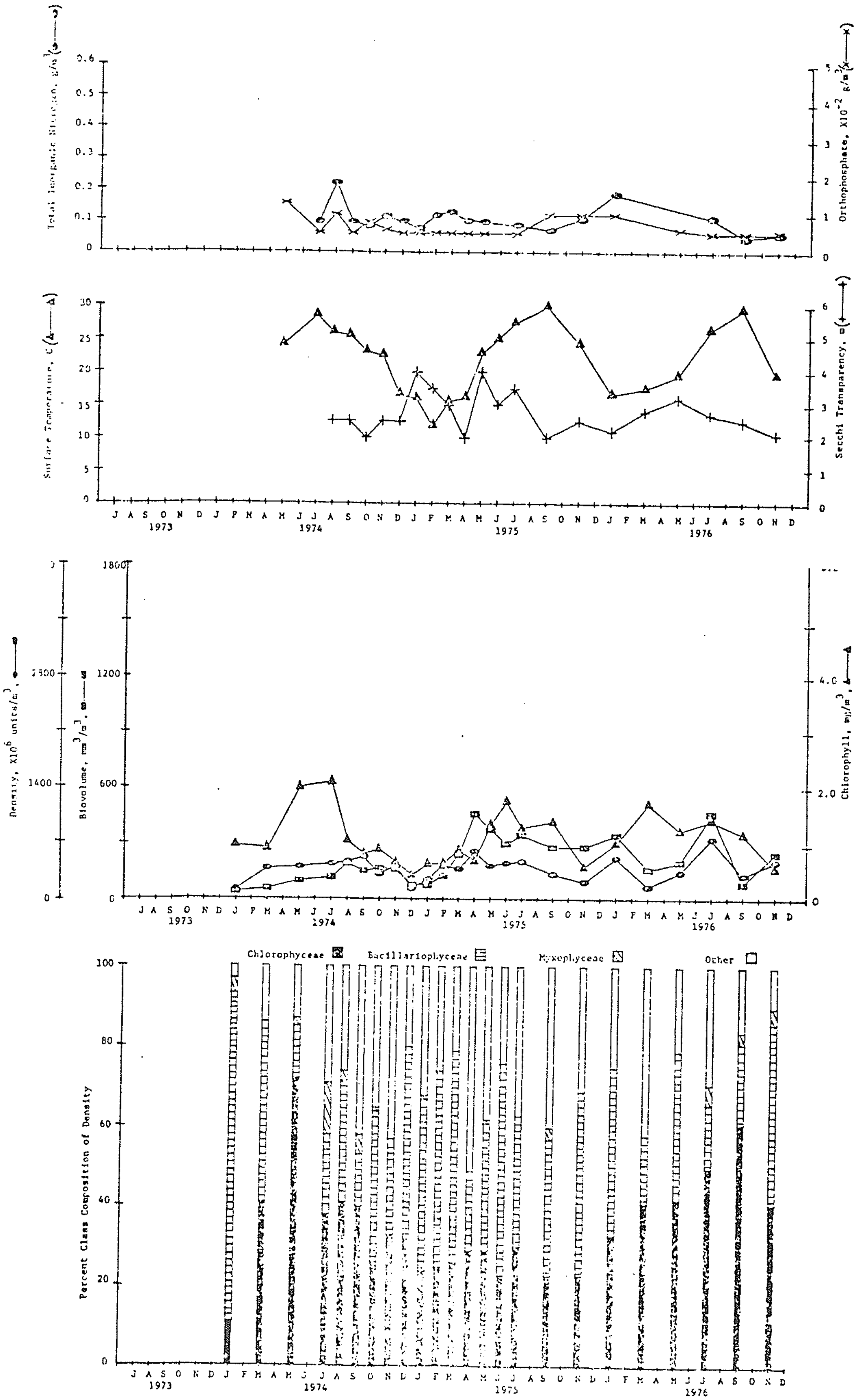


Figure 4-7. Temporal variation of physical-chemical variabiles associated with mean euphotic zone (EZC) phytoplankton indices for Location 508.5, Lake Keowee, SC (total inorganic nitrogen and orthophosphate are averages of three observations between 0.3 and 10m).

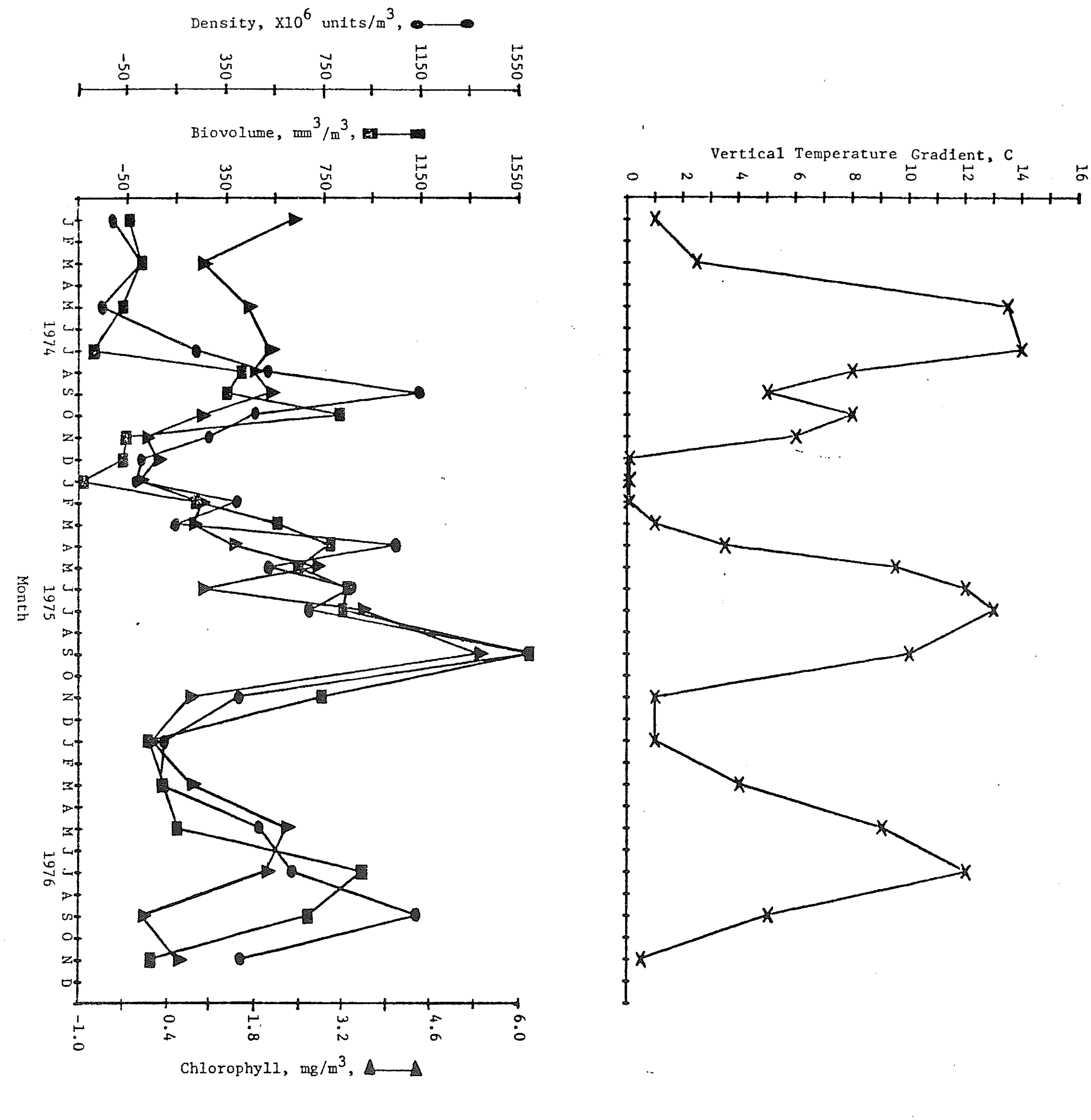


Figure 4-8. Temporal patterns of vertical differences in phytoplankton indices (EZC minus LSD) associated with surface to bottom temperature gradients (0.3 to LSD depth, m) at Location 500.0, Lake Keowee, SC.

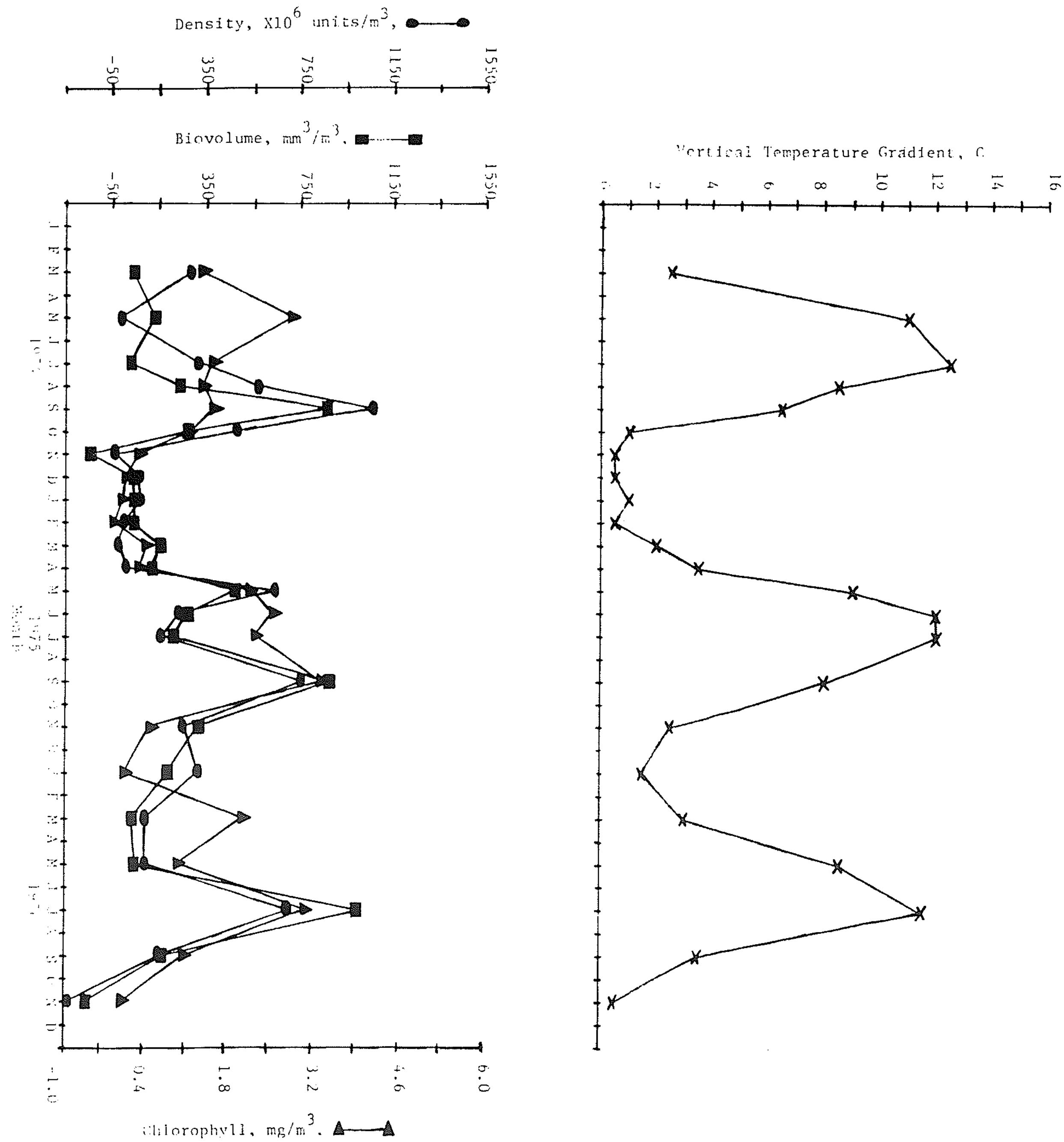


Figure 4-9. Temporal patterns of vertical differences in phytoplankton indices (EZC minus LSD) associated with surface to bottom temperature gradients (0.3 to LSD depth, m) at Location 502.0, Lake Keowee, SC.

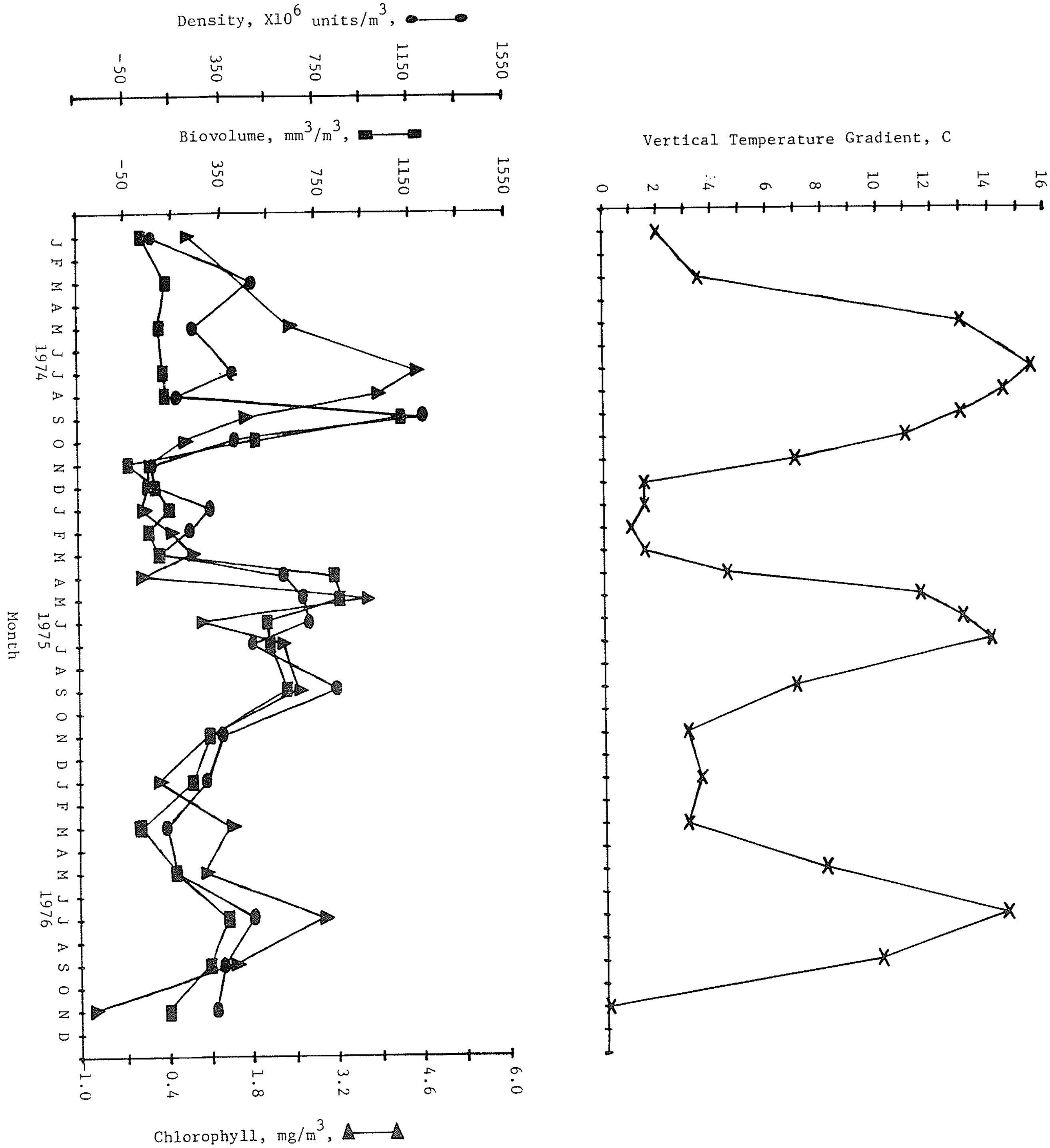
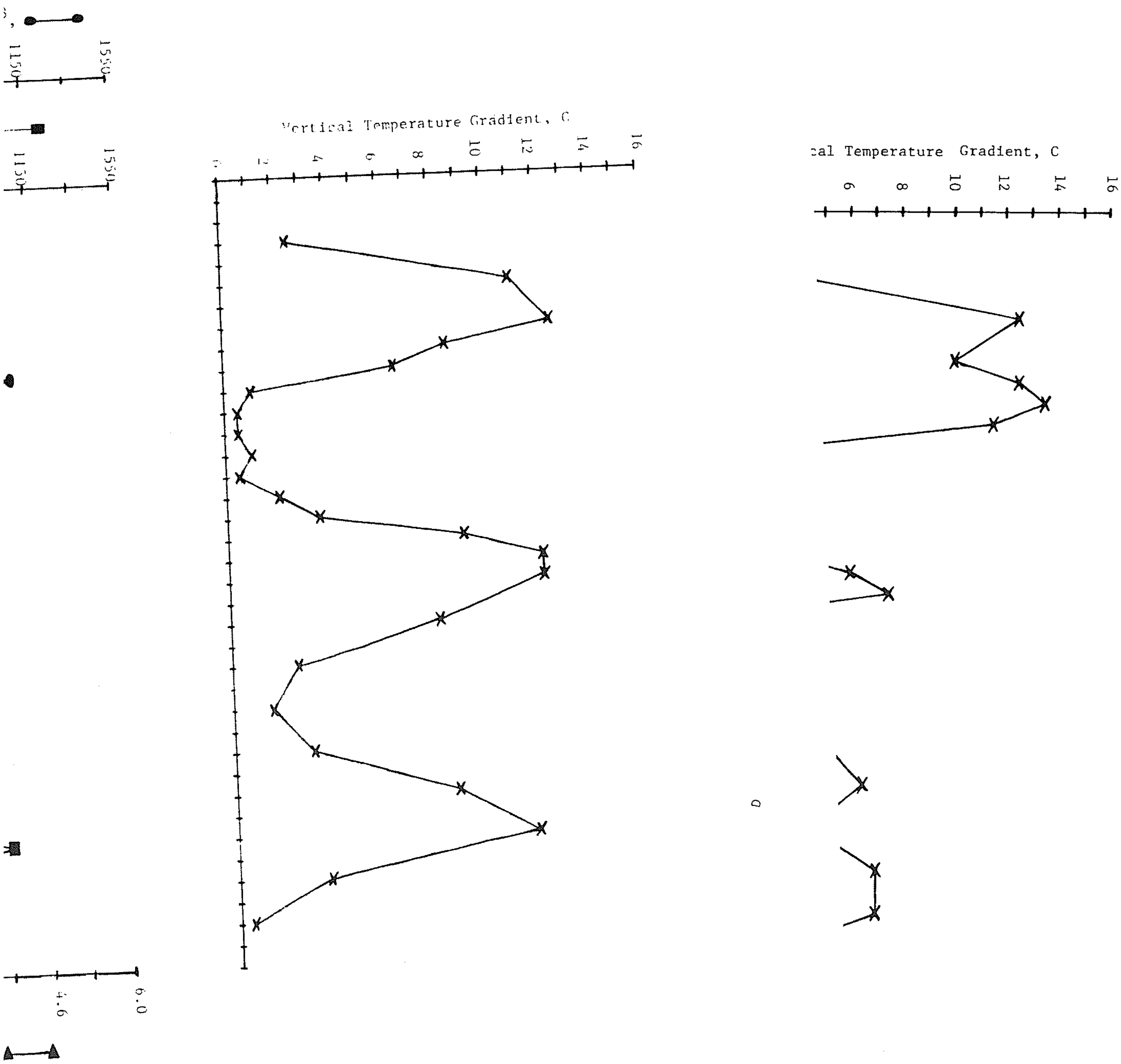


Figure 4-10. Temporal patterns of vertical differences in phytoplankton indices (EZC minus LSD) associated with surface to bottom temperature gradients (0.3 to LSD depth, m) at Location 506.0, Lake Keowee, SC.



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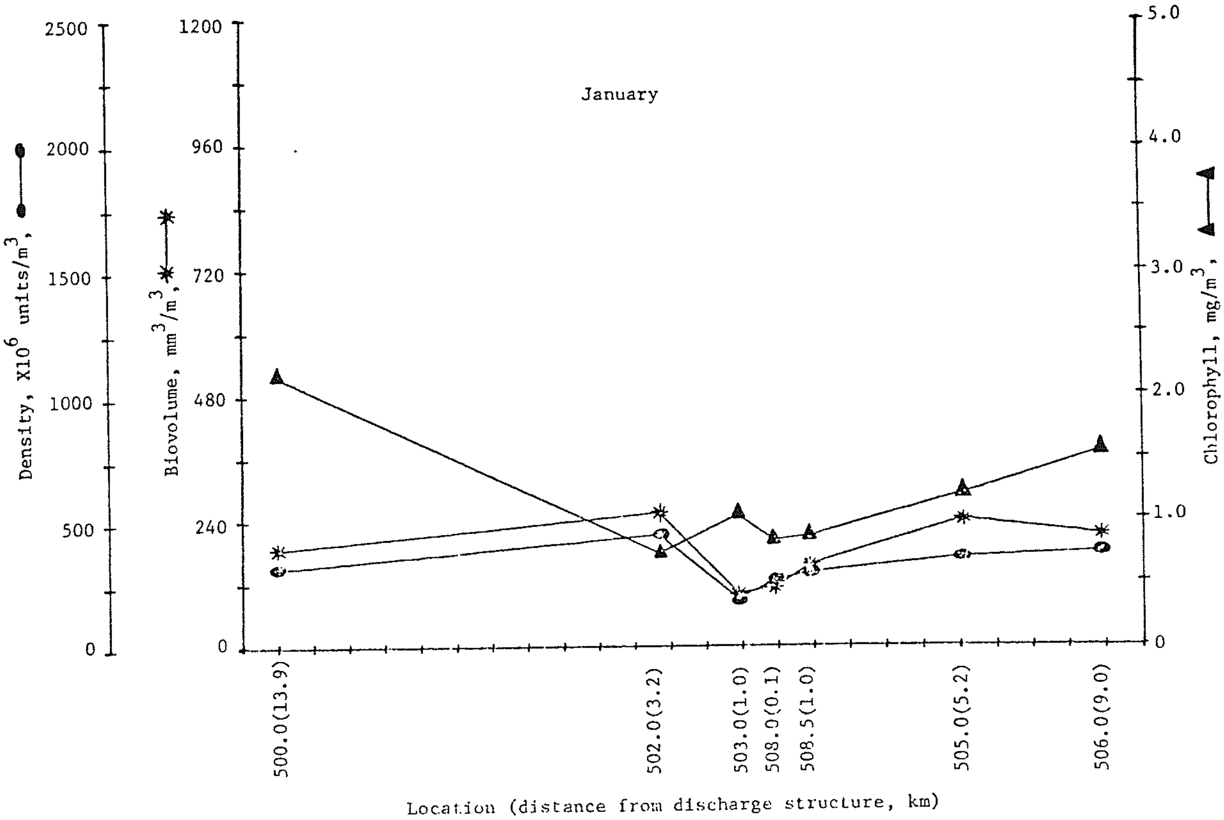


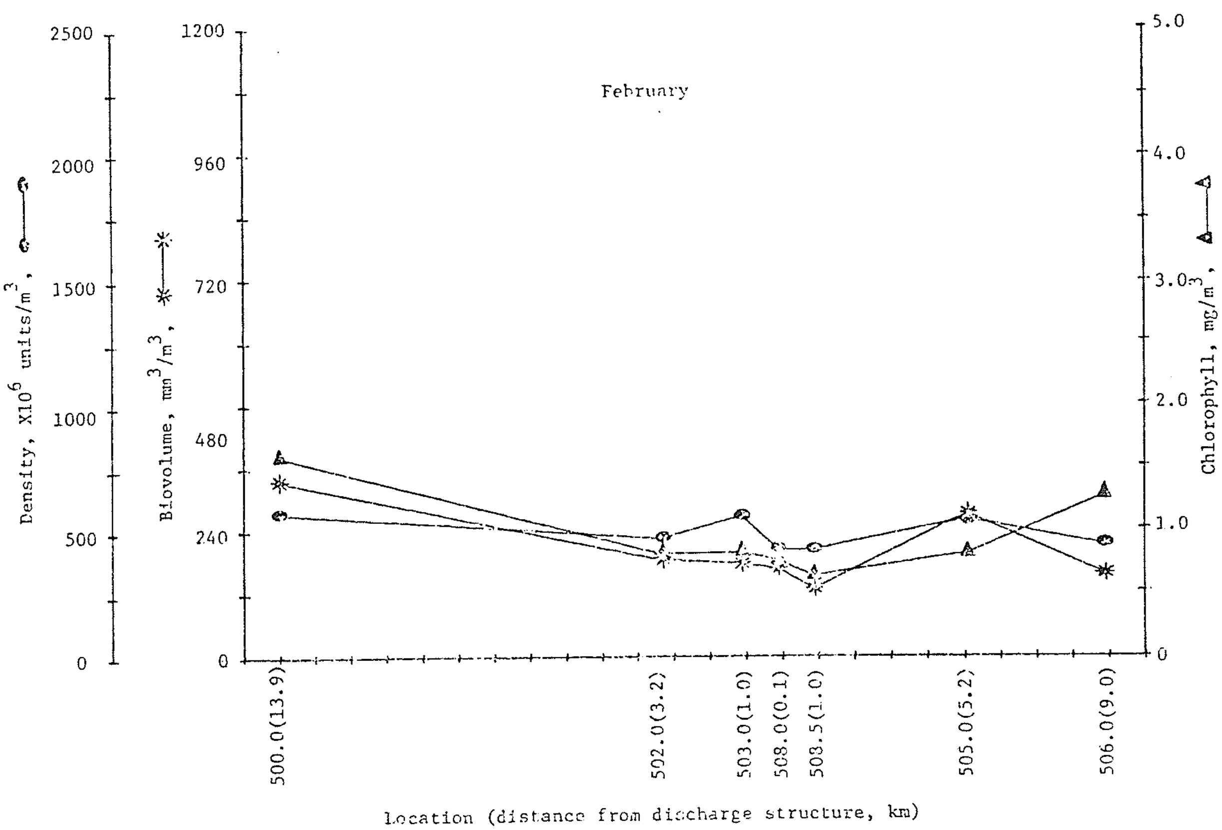
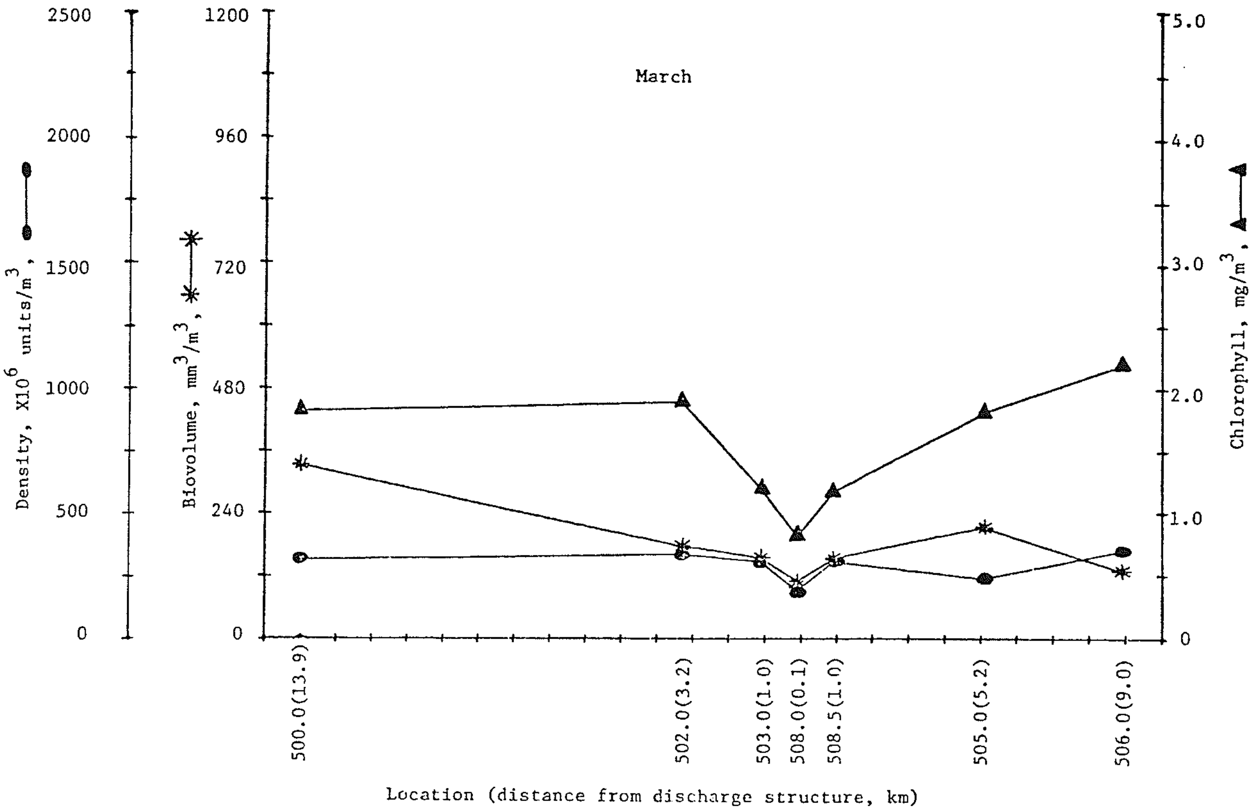


Figure 4-12. Spatial differences of mean euphotic zone (EZC) phytoplankton indices, Lake Keowee, SC for January and February, 1974-1976.



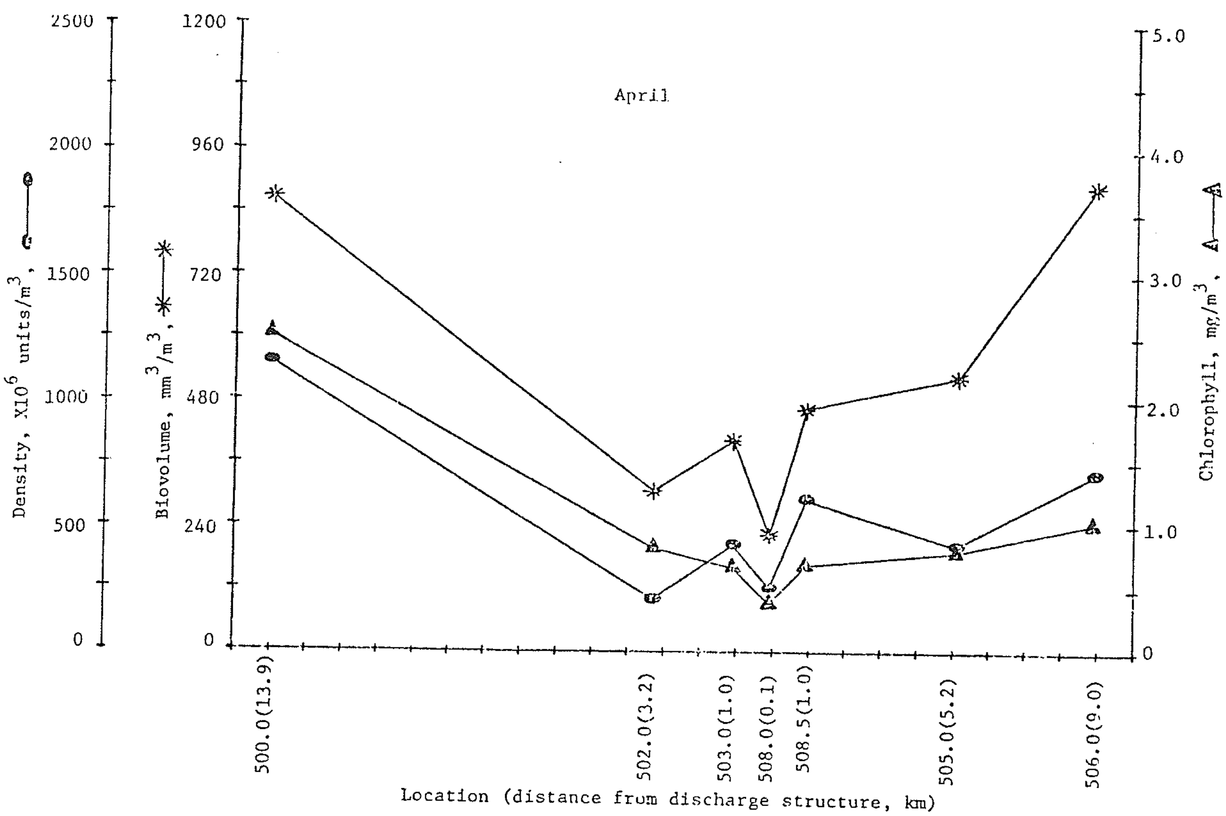


Figure 4-13. Spatial differences of mean euphotic zone (EZC) phytoplankton indices, Lake Keowee, SC for March and April, 1974-1976.

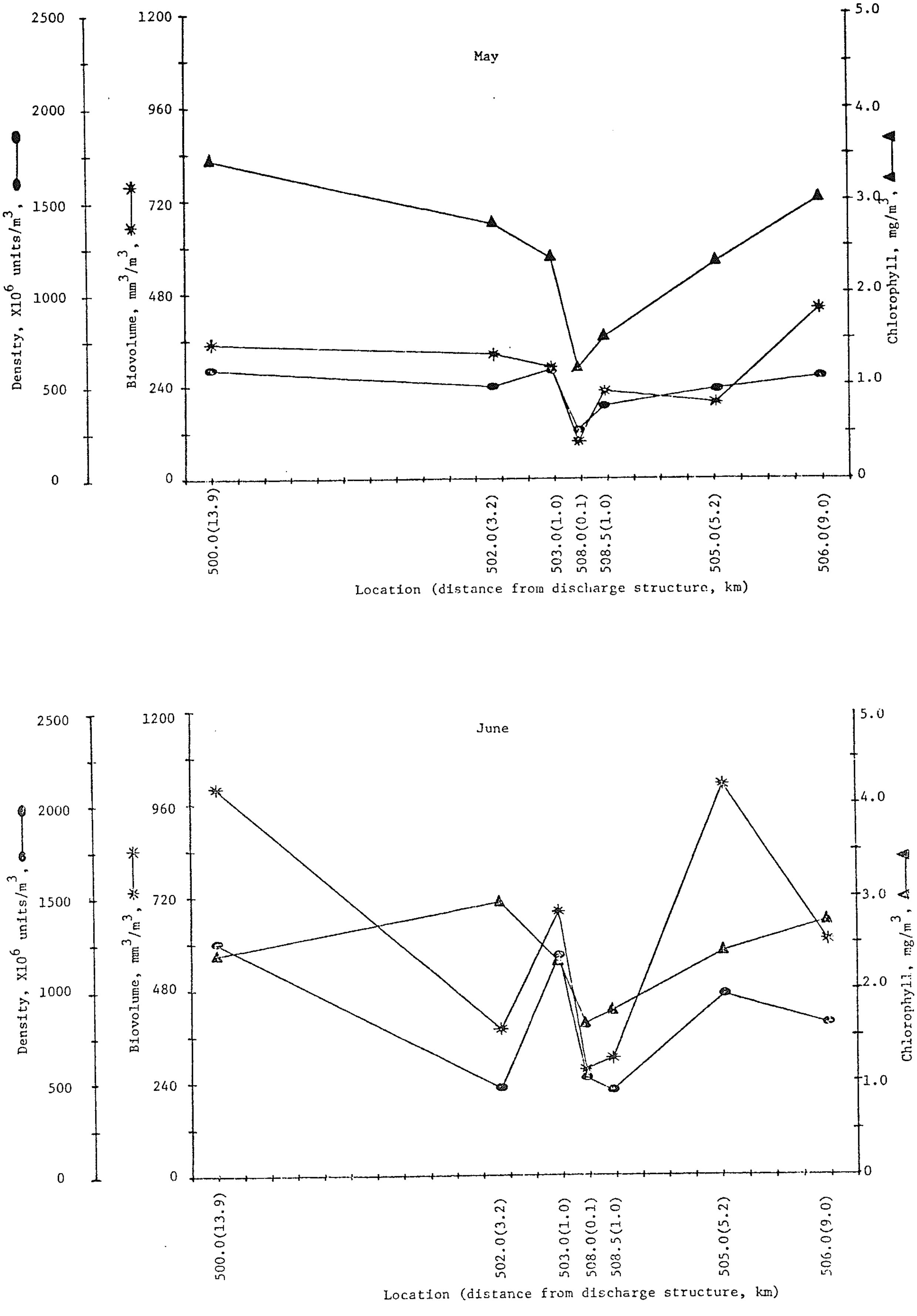


Figure 4-14. Spatial differences of mean euphotic zone (EZC) phytoplankton indices, Lake Keowee, SC for May and June, 1974-1976.

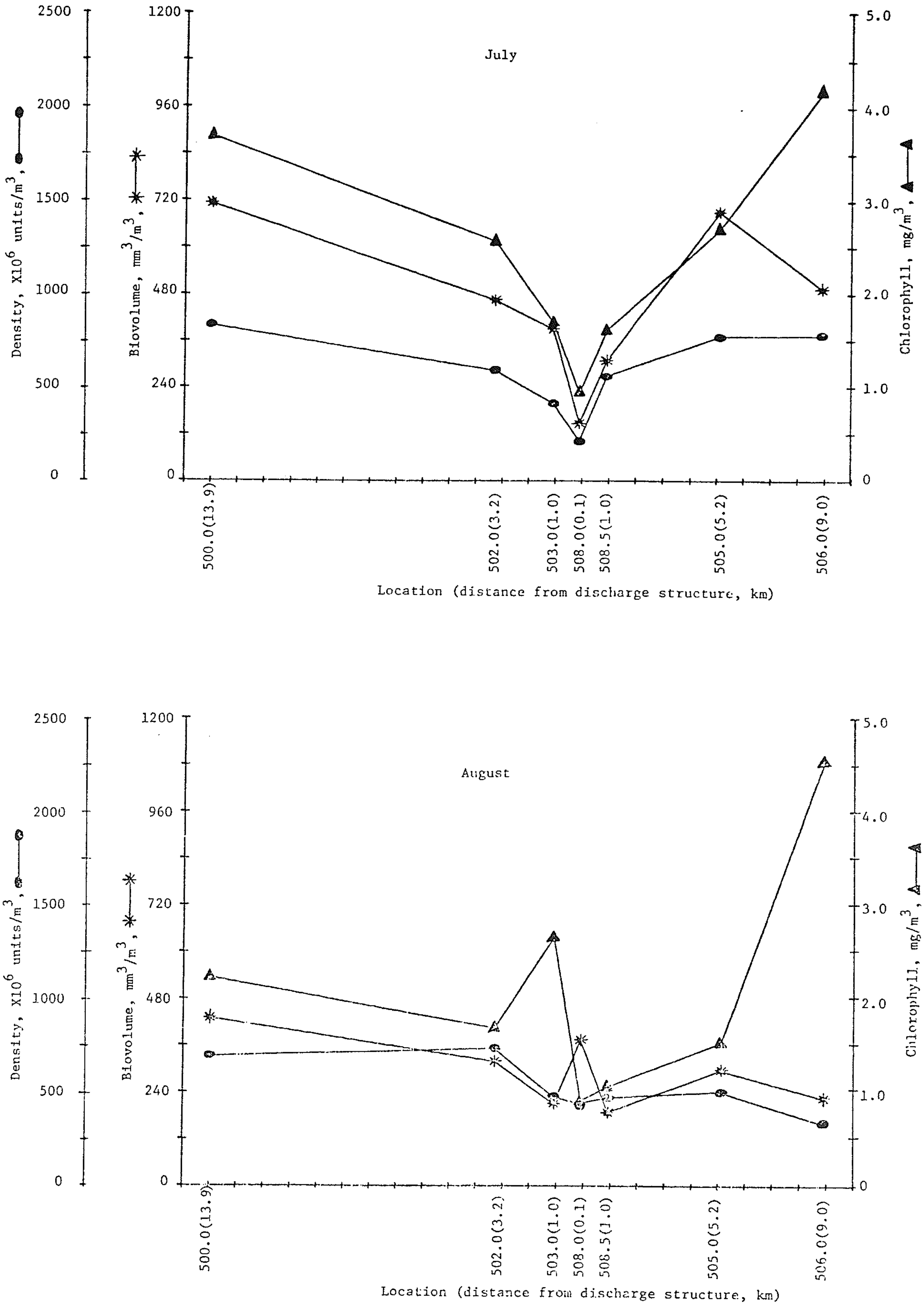
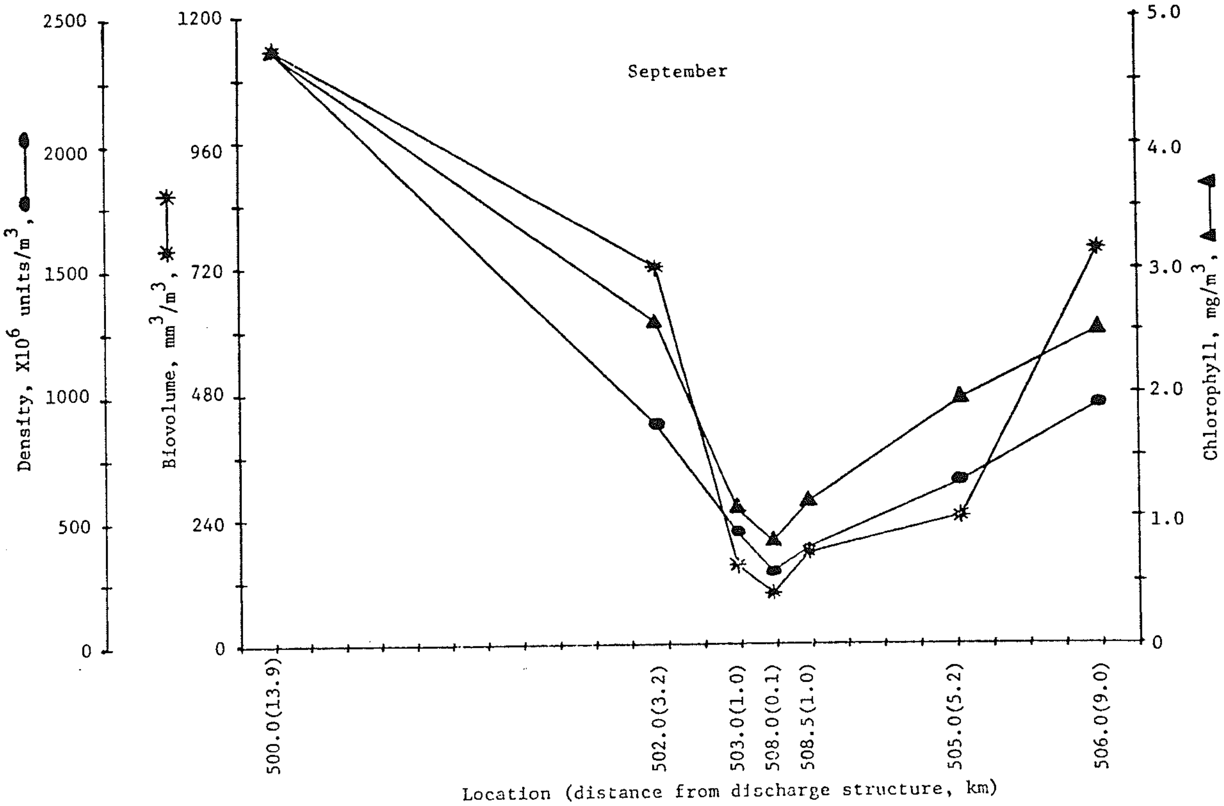


Figure 4-15. Spatial differences of mean euphotic zone (EZC) phytoplankton indices, Lake Keowee, SC for July and August, 1974-1976.



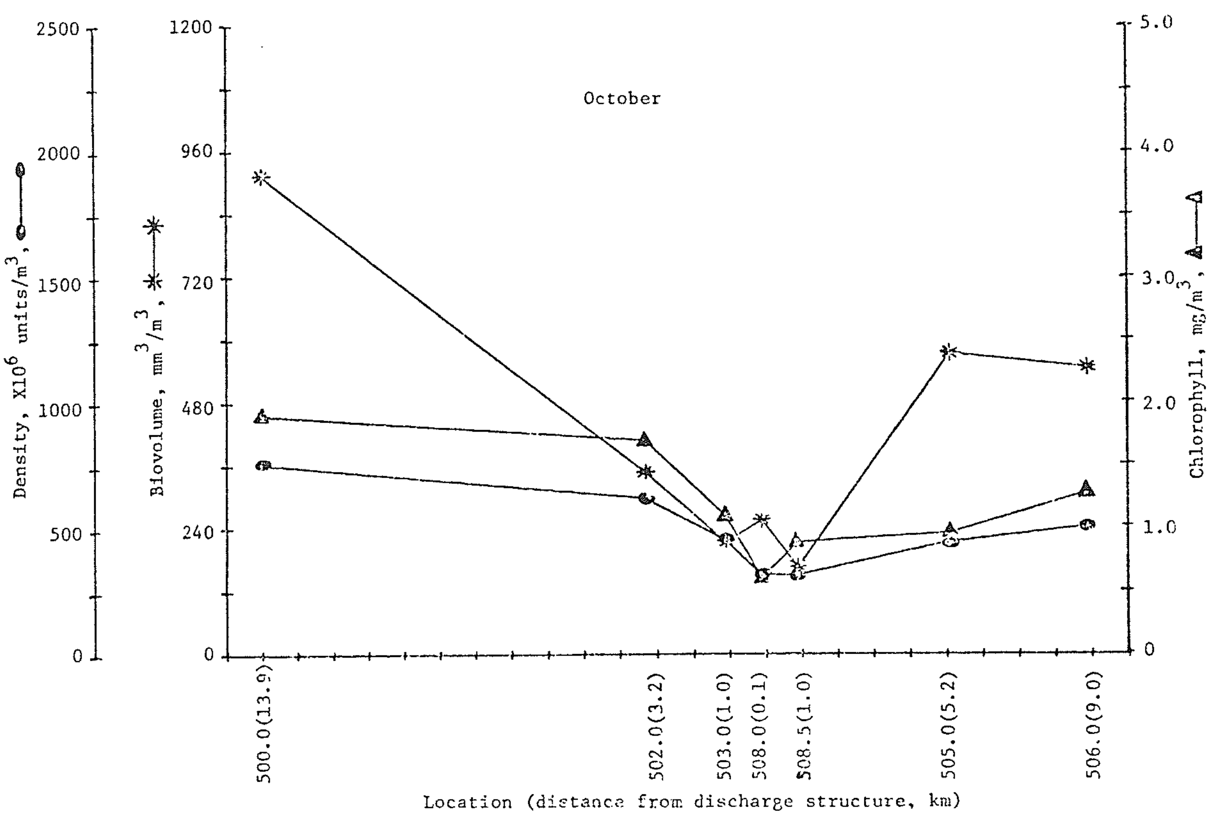
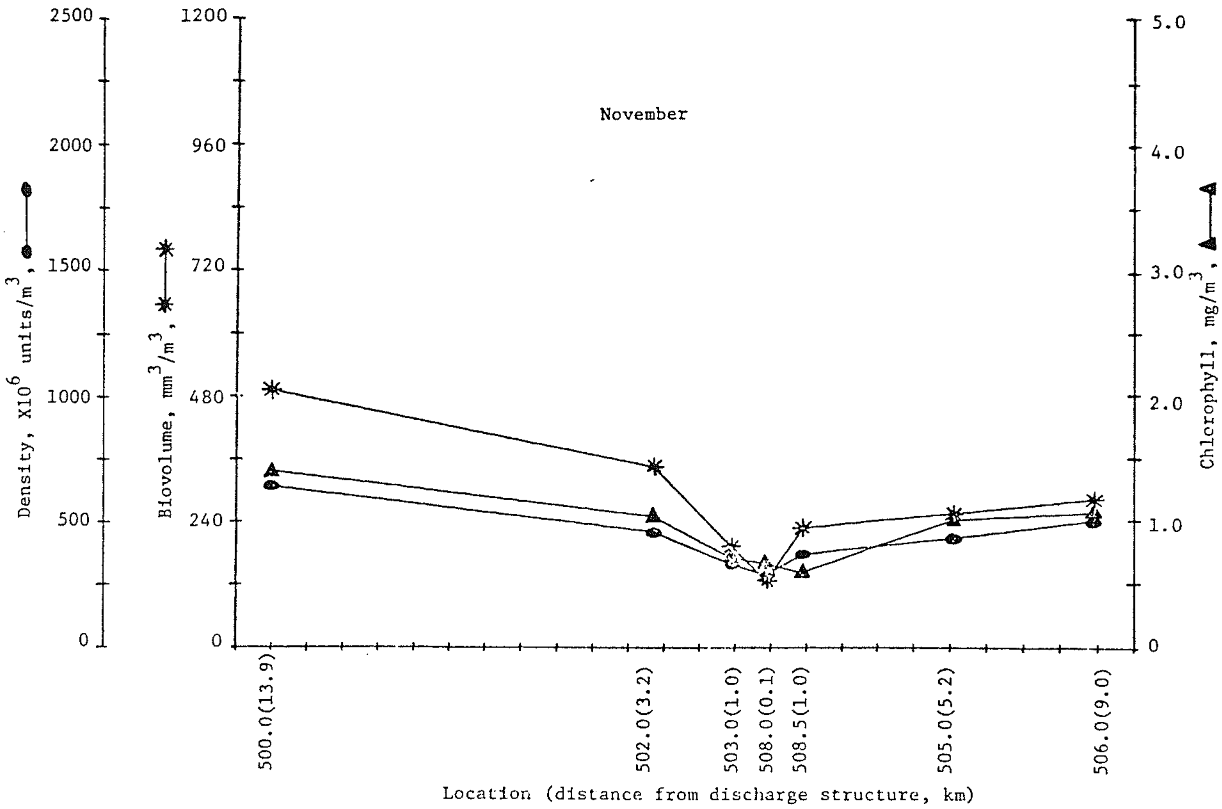


Figure 4-16. Spatial differences of mean euphotic zone (EZC) phytoplankton indices, Lake Keowee, SC for September and October, 1974-1976.



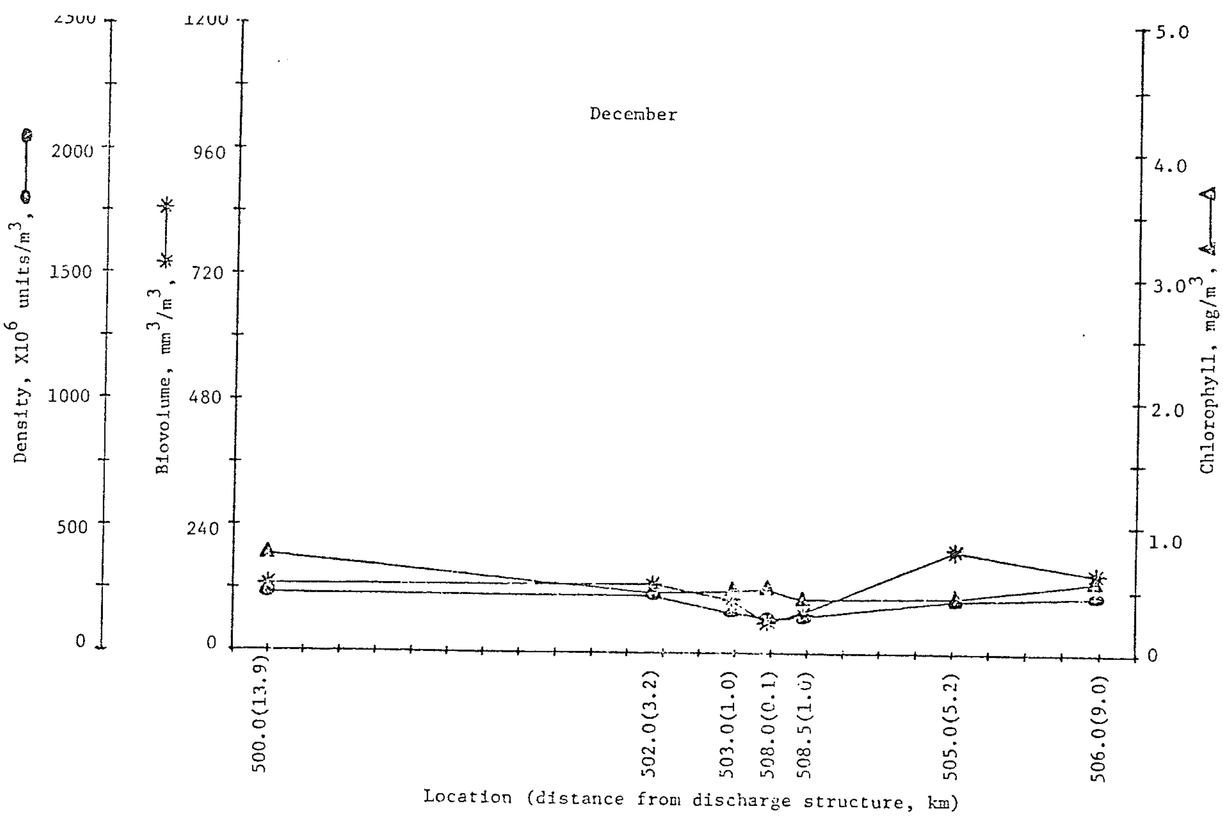


Figure 4-17. Spatial differences of mean euphotic zone (EZC) phytoplankton indices, Lake Keowee, SC for November and December, 1974-1976.

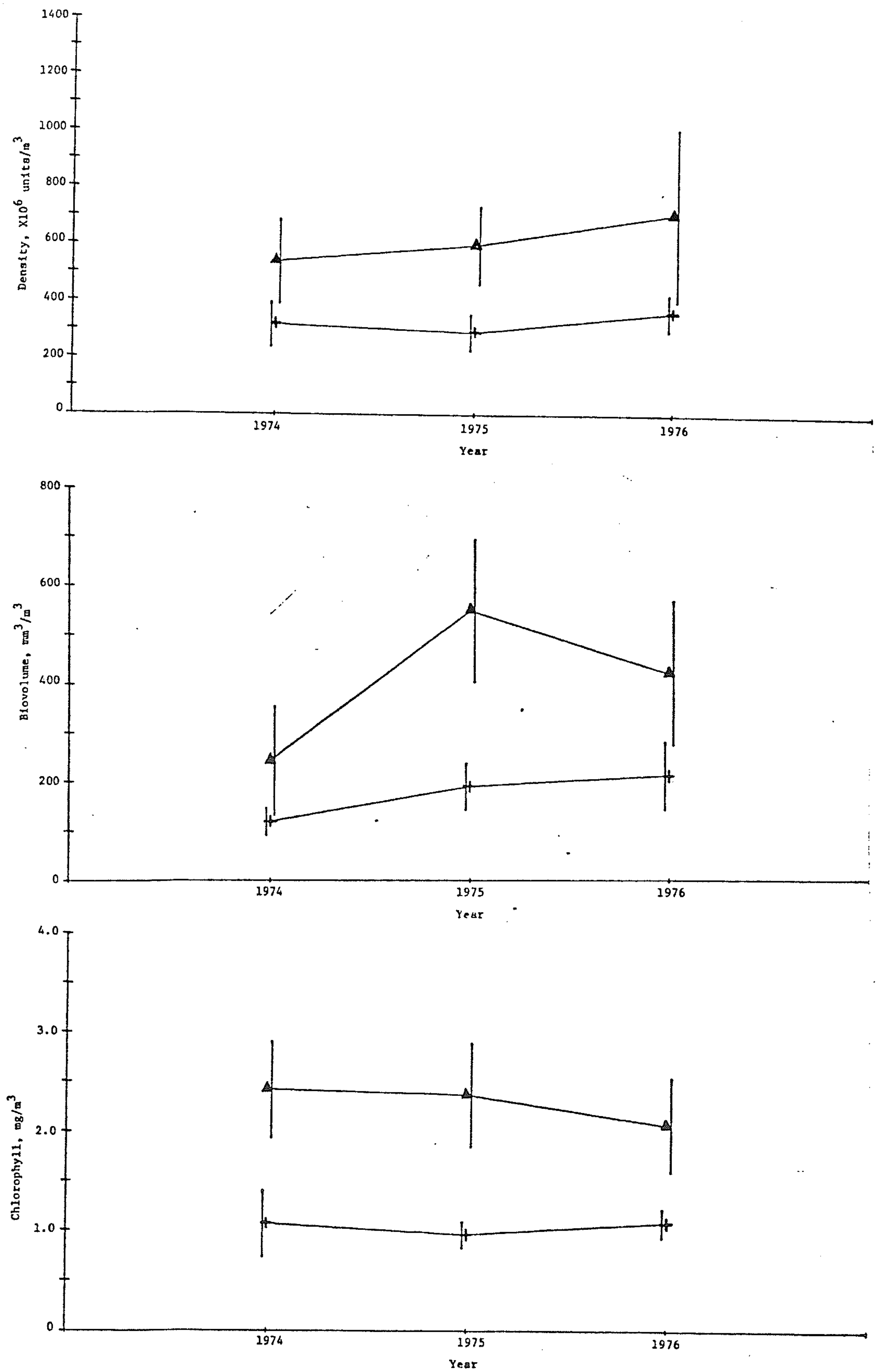


Figure 4-18. Yearly variation of mean euphotic zone (EZC) phytoplankton indices (with 95% confidence interval) for two reservoir areas (reference area ▲——▲ and discharge area +——+) of Lake Keowee, SC, 1974-1976.

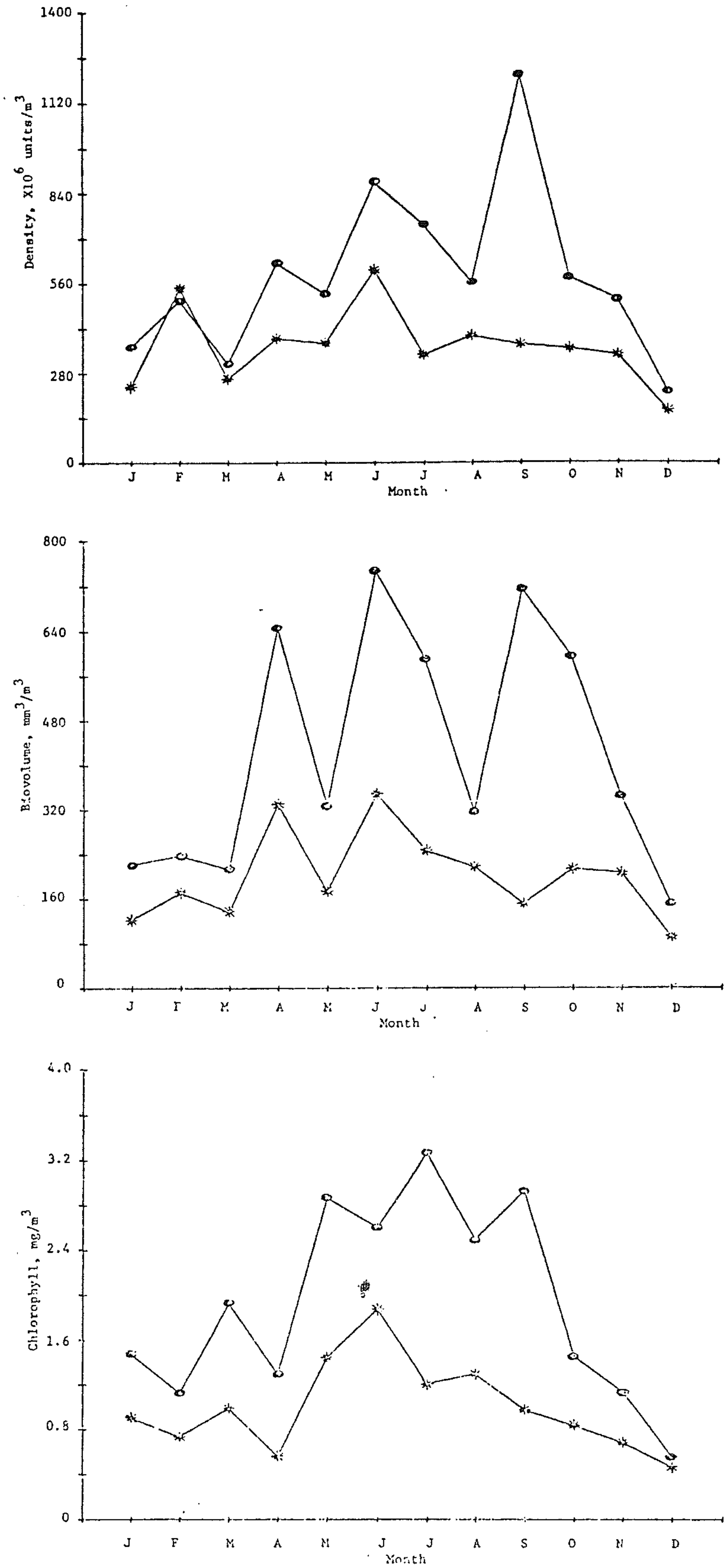


Figure 4-19. Monthly variation of mean euphotic zone (EZC) phytoplankton indices for two reservoir areas (reference area ●——● and discharge area ✱——✱) of Lake Keowee, SC, 1974-1976.

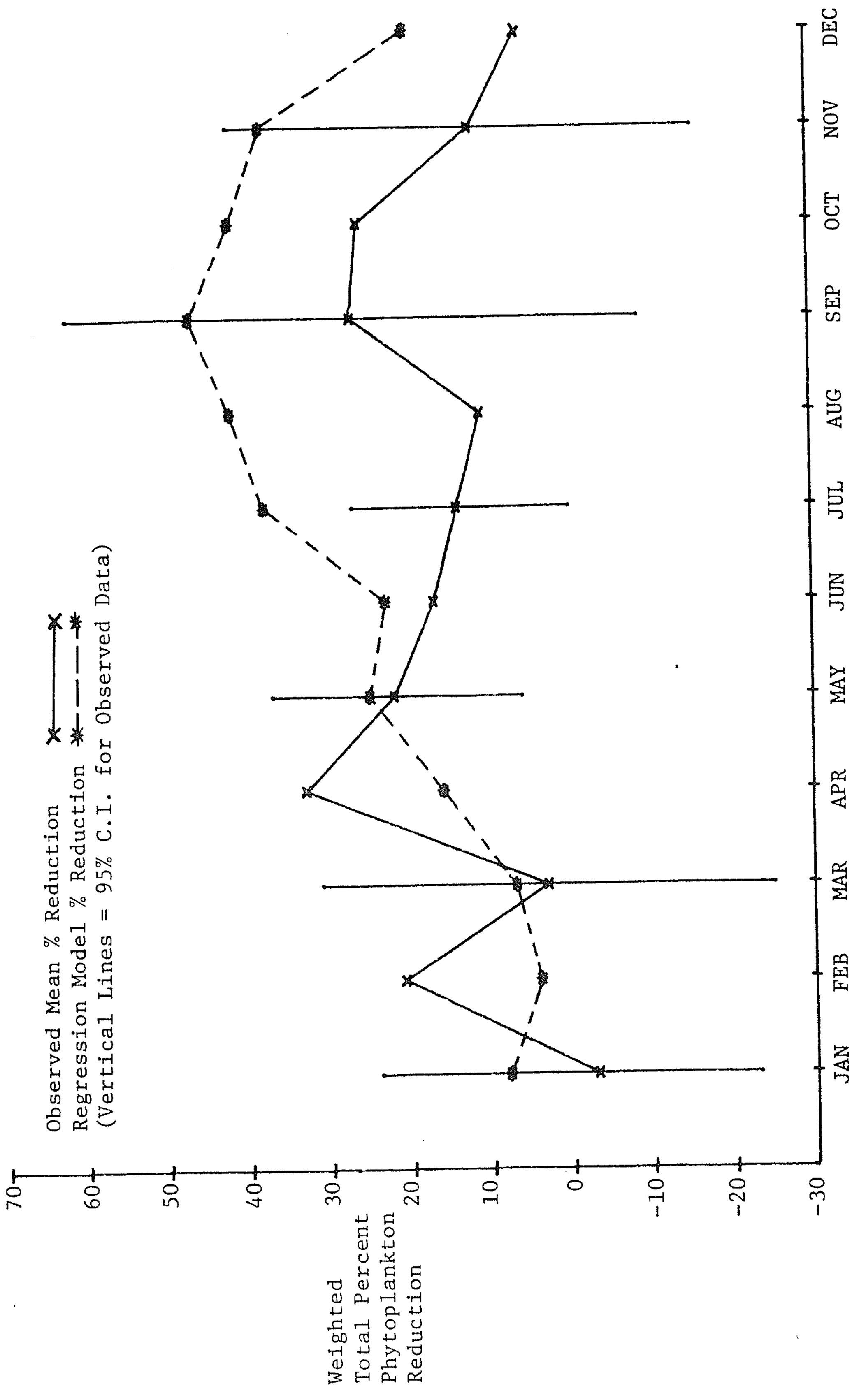


Figure 4-20. Seasonal variation of predicted and observed weighted total percent phytoplankton reductions in Lake Keowee, SC, 1974-1976.

CHAPTER 5 PERIPHYTON

INTRODUCTION

The term "aufwuchs" was used by Sladeckova (1962) to describe all attached organisms in all environments. "Periphyton" has been used to describe all attached aquatic organisms and all associated organisms in the attached matrix (Schwoerbel 1970), while this same term, as used by Wetzel and Westlake (1969) pertains to the algal portion of attached communities. Periphyton has been studied with regard to the productivity, rates of accumulation, chlorophyll content, and species composition in order to indicate major spatial and temporal changes in water quality (Hynes 1970, Odum 1971). Studies of periphyton as indicators of water quality in large artificial impoundments have been made in relation to municipal and industrial water use (Burbank and Spoon 1967, Butcher 1946, Weiss 1971). Also, ecologists have become concerned with the effects of thermal effluents from both conventional and nuclear power plants (Krenkel and Parker 1969). Thermal alterations may cause shifts in algal communities from diatoms and green algae to blue-green species which are not suitable as a food supply (Patrick 1971, Shapiro 1973). Rodgers (1974) found that net productivity of periphyton was highest at the Oconee Nuclear Station (ONS) discharge and was lowest in the intake canal near the skimmer wall, but no studies of species composition or diversity were undertaken.

The objective of this study was to determine the influence of the operation of Oconee Nuclear Station on periphyton communities in Lake Keowee, S. C. Organic accumulation rates have been used as an indicator of gross productivity of the periphyton community from the summer of 1972 through the end of 1976. Diatom proportional counts and relative densities have been determined to indicate species composition and changes in the algal periphyton communities in Lake Keowee from the beginning of 1975 through the end of 1976.

METHODS AND MATERIALS

FIELD PROCEDURES

Periphyton organic accumulation studies were initiated on Lake Keowee, S. C., on June 28, 1972, at Locations 502.0, 504.0 and 506.0. Locations 508.0 (ONS discharge), 501.0, and 500.0 were added later (Fig. 1-1, Chapter 4, Table 5-1). All changes in field and lab procedures, as well as location additions are listed in Table 5-1. Periods of optimum substrate exposure to achieve steady state accumulation vary considerably (Patrick et al. 1954, Newcombe 1949, Squires et al. 1973). Preliminary investigations showed that an exposure period of approximately 59 days was necessary to achieve steady state accumulation. During August of 1974, investigations revealed that steady state accumulation was achieved after approximately 30 days (Table 5-1).

The sampling device used in this study was a stainless steel frame holding four 7.62 cm X 7.62 cm plexiglass slides. Slides were spaced approximately 2.5 cm apart. The frame is designed to minimize shading effects and interference from water currents. Substrate assemblies were suspended at a depth of 1.5 m (Table 5-1). This was the depth at which optimum growth was observed as a result of a preliminary test (Duke Power Company 1973a).

The two center slides were analyzed as replicates for organic accumulation rates, while the two outer slides served as protection. The two outer slides were later analyzed to determine diatom proportional counts and algal densities (Table 5-1).

LABORATORY PROCEDURES

Slides to be analyzed for organic accumulation rates were scraped with a rubber policeman and the attached material was treated and analyzed by the dry and ash-free dry weight procedures in Standard Methods (APHA 1971). The organic accumulation rates were recorded as $mg \cdot m^{-2} \cdot day^{-1}$.

Slides to be analyzed for species composition and density were scraped with a rubber policeman and placed in 60-ml sample bottles. Distilled-deionized water was added to a known volume. Diatom slides were prepared using the nitric acid method of Hohn and Hellerman (1963) and were counted under oil immersion at 1000X and later 1250X (Table 5-1). Approximately 1000 valves were counted when possible and identified to the lowest possible taxon. Additional species found outside the counting area (Whipple grid) were noted as "present" (P).

Major taxonomic keys used for the identification of diatoms included Cleve-Euler (1953), Husted (1930), Patrick and Reimer (1966, 1975), Van Heurck (1896), and Weber (1971). Dr. Charles W. Reimer of the Philadelphia Academy of Natural Science was retained by Duke Power Company as a consultant for taxonomic determinations of diatoms.

Density samples were uniformly resuspended in the sample bottles and a 0.1 ml aliquot from each sample was placed in a Palmer-Maloney counting slide (Palmer and Maloney 1954). Non-diatom organisms were counted and identified to the lowest taxon. Unicellular forms were enumerated as each cell, colonial forms as each colony and filamentous forms were recorded as 18 μ lengths. Taxonomic keys used for the identification of non-diatom forms included Cocke (1967), Kimm (1967), Prescott (1962), Smith (1950), Taft and Taft (1971), Tiffany and Britton (1952) and Whitford and Schumacher (1969). Dr. Larry A. Whitford of North Carolina State University was retained by Duke Power Company to aid in taxonomic determinations of non-diatom forms. Diatoms were enumerated as each frustule, regardless of taxon. A total of approximately 500 units were counted and the number of fields or transects observed was noted. Counts of all algae were converted into densities expressed as $units \cdot cm^{-2}$.

PHYSICAL AND CHEMICAL MEASURMENTS

Physical and chemical data used in the correlation analyses were obtained from water chemistry studies (Chapter 3). Solar radiation data was obtained from the Climatic Atlas of the United States, Department of Commerce, Environmental Science Service Administration, Environmental Data Service, June 1968. ONS flow rates used were those presented in Chapter 2.

DATA ANALYSES

The formula suggested by Lohman (1908) relating a value to the radius of a sphere was used for the graphic presentation of class densities. An index of dominance of algal classes was calculated for each exposure period using a modified method of Shannon (Shannon and Weaver 1963). Density values for each class were averaged over all stations for a given exposure period. An index of dominance for the entire period where density data was available was calculated by the following equation:

$$C_t = \frac{\sum_{n=i}^{i} \left(\frac{N_i}{N}\right)^2 \cdot R_i}{n}$$

Where: C_t = Index over entire period.

$\left(\frac{N_i}{N}\right)$ = Dominance index of Shannon (C_i).

R_i = Inverse rank of C_i for each exposure period.

N_i = Density of class.

N = Total density

n = number of exposure periods

Bartlett's test was used to test data for homoscedasticity (Sokal and Rohlf 1969). Heteroscedastic data were transformed and retested for homoscedasticity. Once homoscedastic, variables were analyzed using the two way analysis of variance (ANOVA) procedure calculated with the Statistical Analysis System (SAS) of Barr et al. (1976). Sample period, location, and interaction effects were tested by two way ANOVA.

Significant simple main effects (Keppel 1973), as well as variables showing significant differences when no interactions were present, were analyzed using the Least Significant Differences (LSD) test (Carmer and Swanson 1973).

Correlation analyses were performed using the Spearman coefficient of rank correlation (Conover 1971) calculated with SAS of Barr et al. (1976).

RESULTS AND DISCUSSION

ORGANIC ACCUMULATION RATE

Organic accumulation rates for each station and means for all locations and sample periods are presented in Table 5-2. Figure 5-1 shows trends in organic accumulation rates at all stations for all sample periods through 1976.

The highest organic accumulation rate for the study was 155.3 mg-m$^{-2}\cdot$day^{-1} at Location 506.0 for the period ending June 29, 1976. The lowest rate was 0.4 mg-m$^{-2}\cdot$day^{-1} at Locations 501.0 and 502.0 for the period ending December 5 and April 5, 1973, respectively (Table 5-2).

General trends observed for organic accumulation rates at Lake Keowee locations showed maximum rates occurring during periods of warmer temperatures and high solar radiation while lower rates were noted during cooler months with low solar radiation. Location 506.0 generally had the highest rates, followed by

Locations 500.0 and 508.0. Organic accumulation rates at Locations 500.0, 501.0, and 506.0 were probably positively influenced to an extent by the presence of Sida crystallina O. F. Muller, a benthic cladoceran which was observed on slides from these locations during warmer periods in 1976. Location 502.0 (outside the skimmer wall) generally had lower accumulation rates than other locations. Rodgers (1974) found that the highest rates of periphyton production occurred at the discharge while the lowest rates were observed in the intake near the skimmer wall.

A significant interaction in organic accumulation rates was noted among sample periods and locations (Table 5-3). Significant location effects were noted for periods ending in December 1972; January, March through June and October through November, 1974; May through October and December 1975; and January, April through July and September through November 1976.

Results of the correlation analysis are presented in Table 5-4. A significant correlation ($r>0.5$, $p<0.01$) occurred between organic accumulation rates and temperature. An inverse correlation ($r>0.5$, $p<0.01$) was noted with dissolved oxygen as would be expected (Odum 1971). There were also significant positive correlations ($r>0.6$, $p<0.01$) between organic accumulation rates and total periphyton density, diatom densities and green algal densities.

Temperature and light were probably the most important factors in determining seasonal variations in organic accumulation rates at all locations (Figs. 5-2 through 5-8). Hynes (1970) found that the effects of temperature on periphyton are difficult to distinguish from those of light, but these interacting factors are generally the most important in determining seasonal variations.

Yearly integrated organic accumulation averages per station and yearly integrated BTU and flow rate means at ONS are plotted in Fig. 5-9.

As ONS plant capacity increased in 1974, organic accumulation rates increased. When ONS achieved maximum capacity in 1975, organic accumulation rates decreased at all locations but 504.0. In 1976, organic accumulation rates increased or stayed approximately the same at all locations except 504.0 which showed a sharp decrease. Organic accumulation rates also decreased closer to the plant, with the exception of Location 508.0. Nutrient profiles show similar patterns (Chapter 3). The decrease in the spatial and temporal variability and the decreased concentrations of nutrients in Lake Keowee caused by induced mixing by ONS and Jocassee Pumped Storage operations was primarily responsible for the trends in organic accumulation rates at all locations except Location 508.0. Higher temperatures during the winter, and consistent current were responsible for relatively high rates of accumulation at Location 508.0 (Fig. 5-9).

COMMUNITY COMPOSITION

A total of 249 algal taxa were identified from Lake Keowee locations, including 57 genera, 204 species and 66 varieties (Duke Power Company 1976, Table 5-5).

There were 29 genera, 144 species and 61 varieties of diatoms (Bacillariophyceae) identified from Lake Keowee locations. Diatoms were the most abundant forms, contributing 67.4% to the mean total density and having a dominance index of

2680.8×10^{-3}. The green algae (Chlorophyceae) included 16 genera, 38 species and 5 varieties and contributed 30.5% to the mean total density. The Chlorophyceae had a dominance index of 207.6×10^{-3}. There were 5 genera and 10 species of blue green algae (Myxophyceae) identified and this class composed 1.8% of the mean total density with a dominance index of 1.0×10^{-3}. The other classes listed contributed less than 0.2% to the mean total density and their dominance indices were less than 0.12×10^{-3} (Table 5-6).

TOTAL PERIPHYTON

Total periphytic algal densities ranged from a maximum of approximately 640,000 units$\cdot$cm^{-2} at Location 508.0 for the period ending August 30, 1976, to a minimum of 2210 units$\cdot$cm^{-2} at Location 500.0 for the period ending January 31, 1976 (Table 5-7).

A significant interaction in total densities was noted among sample periods and locations (Table 5-3). The simple main effects test showed that significant location effects were present for two sample periods (January 31 and May 3, 1976). Differences between sample periods were due to high densities during summer and fall (July through November) and very low densities during winter and spring (December through May). Observed relative densities were usually highest at Location 508.0 and lowest at Location 502.0 (Table 5-7). Significant ($r>0.5$, $p<0.01$) positive correlations were observed between total densities and temperature, conductivity, and organic accumulation rates. A significant negative correlation ($r>0.5$, $p<0.01$) was noted with dissolved oxygen (Table 5-4). As with organic accumulation rates, temperature and light were the most important factors in determining seasonal variations of periphyton densities.

Seasonal and spatial trends of periphyton densities were similar to those of organic accumulation rates (Figs. 5-2 through 5-8), and a good correlation ($r = 0.737$, $p<0.01$) was noted between the two (Table 5-4). Some variation in magnitude and frequency of peaks did exist between densities and organic accumulation rates (Figs. 5-2 through 5-8). This was attributed to the presence of some constituent of the biomass other than algae, probably benthic micro-invertebrates.

Decreases in spatial and temporal variability and in the concentrations of nutrients caused by the operation of ONS were the primary factors influencing spatial trends of periphyton densities at locations in Lake Keowee.

CLASS VARIATIONS

Results of the ANOVA for diatom densities were the same as those with total densities and periods of significant station effects were the same. Significant correlations were also similar to those with total density data (Tables 5-3 and 5-4). This was expected, since diatoms comprised approximately two-thirds of the total density.

Diatoms were usually more abundant in summer and fall (July through October) and were least abundant, during winter and early spring (December through March) (Figs. 5-2 through 5-8). Proportionally, diatoms were more dominant during the cooler months (December through May) and generally contributed over 80% to the total densities. During warmer months (June through October) diatoms often contributed less than 70% to total densities (Duke Power Company 1975b, 1976). Optimum temperatures for diatom development generally range from 14-22 C (Whitford and Schumacher 1963). It was during periods with temperatures in this range that diatoms attained high proportions.

A significant interaction in green algal densities was noted among sample periods and locations (Table 5-3). The simple main effects test indicated significant location effects for periods from September through October and from April through July. Differences among sample periods were due to high densities during warm months of high solar radiation (June through September) and low densities during cool months of low solar radiation (December through April) (Figs. 5-2 through 5-8).

Significant correlations ($r>0.5$, $p<0.01$) were noted with the same chemical factors that correlated well with total densities and diatom densities (Table 5-4).

The highest green algal density observed was approximately 320,000 units$\cdot$cm^{-2} for August 30, 1976, at Location 508.0. The highest diatom density (307,000 units$\cdot$cm^{-2}) was also observed at this location for the same period (Fig. 5-6). This was probably due to a substantial increase in ammonia which was observed at this time, and not an effect on ONS discharge temperatures since temperatures among Lake Keowee locations varied less than 1 C during August (Chapter 2). Chlorophyceae were most abundant at Location 508.0 (Fig. 5-6).

The most dominant green alga was *Mougeotia* spp. which was especially important at Location 508.0. It often contributed over 30% to the total periphyton assemblage during warm months at this location (Duke Power Company 1975b, 1976). *Diogenes* sp. (*Nannochloris* sp.) was found to contribute over 30% to total densities at Locations 500.0 and 501.0 for September 3, 1975, and September 29, 1976 (Duke Power Company 1976).

The two-way ANOVA for blue-green algal densities indicated significant differences between sample periods only (Table 5-3). No significant correlations were noted (Table 5-4). The LSD test indicated that differences were due primarily to extremely low populations during the cool months (December through February) (Figs. 5-2 through 5-8). Maximum densities of blue greens were observed from June through October and the highest density was approximately 46,000 units$\cdot$cm^{-2} at Location 502.0 for the period ending October 30, 1975 when *Chroococcus minutum*, a coccoid blue green, contributed 49% to the periphyton assemblage.

Temperatures at the ONS discharge were never high enough to cause a shift from diatoms and green algae to blue greens since blue greens typically become dominant at temperatures over 35 C (Patrick et al. 1969). Also, low pH conditions in the discharge tend to favor green algae and acidophilous diatoms by making more CO_2 available (Shapiro 1973). In fact, Location 508.0 usually had lower blue green densities than other locations. Green algae and diatoms are considered more desirable than blue greens as they are within the food chain and do not form floating scums (Shapiro 1973). Blue greens were not generally an important part of the peiphytic algal communities at Lake Keowee sampling locations.

DIATOM COMMUNITY STRUCTURE

Achnanthes microcephala was the most important species among periphytic diatom assemblages throughout 1975 and 1976, especially at Locations 500.0 and 501.0 where it often contributed over 80% to diatom assemblages. A. microcephala did not show such high percentages at Location 508.0 and seldom contributed over 50% to the diatom community (Duke Power Company 1975a and b, 1976). This species is considered ubiquitous and eurytrophic (Patrick and Reimer 1966). Cholnoky (1968) characterizes it as the best indicator of permanent oxygen concentrations in weakly acidic water. Its lower proportions at Location 508.0 may be due to lower dissolved oxygen concentrations in the discharge (Chapter 3). It is also possible that this species, which is limnophilous to limnobiontic (Lowe 1974) was competing against other species which were rheophilous and developed better in the current present in the discharge cove.

Other common species included Anomeoeneis vitrea and Melosira distans (Duke Power Company 1975a and b, 1976) which have been described as ubiquitous under a wide range of ecological conditions (Patrick and Reimer 1966, Lowe 1974). The occurrence of these species could not be related to the operation of ONS. Species of Synedra (all varieties of S. rumpens and an unidentified species) were common at all locations but were most important at Location 508.0 from December through March (Duke Power Company 1975a and b, 1976). These species have been characterized as present under a wide temperature range and as "indifferent" to pH (Lowe 1974).

Gomphonema parvulum and two species of Tabellaria (T. fenestrata and T. flocculosa) were observed in large numbers at Location 508.0. G. parvulum has been characterized as rheophilous (Wallace and Patrick 1950) and Tabellaria spp. have been described as acidophilous in oligotrophic to beta-mesosaprobic environments (Lower 1974). Their presence in the discharge was probably due to the effects of current.

Certain species of Eunotia (E. flexuosa and E. naegleii) were important at Location 508.0 and they were generally observed in greatest numbers during warmer periods (Duke Power Company 1975a and b, 1976). These species have been characterized as acidolphilous in water of low mineral content (Patrick and Reimer 1966, Lowe 1974).

Species abundance at Location 508.0 has been greater than at other locations and certain taxa observed there, such as Gomphonema parvulum, are more often associated with stream habitats (Hynes 1970, Wallace and Patrick 1950). The consistent current at Location 508.0 enhanced the development of a greater variety of species since the water is made "physiologically richer" due to the constant renewal of nutrients at the surfaces of organisms (Ruttner 1953). During cool months, higher temperatures were additionally responsible for the maintenance of a larger number of taxa.

Acidophilous forms such as species of Eunotia and Tabellaria were more important at the discharge as a result of more acidic conditions due to the operation of ONS during stratified periods. The types and proportions of diatom species observed at Lake Keowee sampling locations are those generally associated with circumneutral, oligotrophic lakes (Hutchinson 1967).

SUMMARY AND CONCLUSIONS

Seasonal trends of organic accumulation rates and algal densities were primarily a function of meteorological conditions. Organic accumulation rates, total densities and major class densities were highest during warm months of high solar radiation and lowest during cool months of low solar radiation.

The highest organic accumulation rates were noted at Location 506.0, while the highest densities were observed at Location 508.0. Minimum rates of accumulation and densities were usually observed at Location 502.0. Accumulation rates at Locations 500.0, 501.0, and 506.0 may have been positively influenced by the presence of benthic microinvertebrates.

Spatial and yearly trends of organic accumulation rates were similar to those of nutrient concentrations, and spatial and seasonal trends of algal densities were similar to those of organic accumulation rates. The stabilization of nutrients brought about by the operation of ONS was primarily responsible for yearly and spatial trends of organic accumulation rates and spatial trends of periphyton densities at locations in Lake Keowee. The most pronounced effects were observed in 1975 when ONS was operating at a high capacity factor. The lowest organic accumulation rates were observed in 1975. Lower organic accumulation rates and densities were observed closer to the plant with the exception of Location 508.0.

Higher rates of accumulation and densities at Location 508.0 were a result of thermal discharge during cool, destratified periods when temperatures were lower at other locations. During warm, stratified periods, the effects of current caused increased organic accumulation rates, densities, and taxa abundance. Increased nutrient availability and more acidic conditions brought about by the operation of ONS during stratified periods also caused a shift in diatom species toward more acidophilous forms such as *Eunotia* spp. and *Tabellaria* spp. and certain rheophilous forms such as *Gomphonema parvulum*.

Diatoms were the most abundant forms, contributing over 67% to the mean total density. The Chlorophyceae constituted over 30% to the mean total density and blue greens contributed less than 2% to the mean total density. At Location 508.0, green algae, predominantly *Mougeotia* spp. dominated periphyton assemblages in August and September of 1975 and 1976. Blue green algae were not enhanced by the operation of ONS.

Based on periphyton species composition, densities and organic accumulation rates observed on artificial substrates, Lake Keowee can be classified as a circumneutral, oligotrophic lake. Although year to year and spatial differences were observed, the operation of ONS did not significantly alter the trophic status or water quality of Lake Keowee with respect to periphyton community.

RECOMMENDATIONS

Based on the above conclusions, the following recommendations are submitted:

Since organic accumulation rates, algal densities, and major class densities display consistent seasonal patterns and since the most pronounced effects of ONS on periphyton have been observed and documented, periphyton monitoring should be discontinued at locations in Lake Keowee.

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Table 5-1

Periphyton methods changes on Lake Keowee, S. C. from August 25, 1972 through June 29, 1976.

Date	Method Change	Reference
8-23-72	Added Location 508.0	Duke Power Co. 1973a
12-14-72	Added Location 501.0	Duke Power Co. 1973a
4-5-73	Orientation of substrates changed from vertical to horizontal	Casterholz 1960 Duke Power Co. 1973a
7-26-73	Added Location 500.0	Duke Power Co. 1973b
8-29-74	Exposure period reduced to approximately 30 days	Duke Power Co. 1974b
1-28-75	Two outer slides composited for diatom proportional counts	Duke Power Co. 1975a
8-4-75	Two outer slides composited for relative density counts	Duke Power Co. 1975b
3-1-76	Each outer slide analyzed as a replicate for both diatom and relative density counts. Magnification for density counts increased from 400X to 500X. Magnification for diatom counts increased from 1000X to 1250X	Duke Power Co. 1976
6-29-76	Outer slides preserved with M^3 and placed in sealed plastic containers in the field	Duke Power Co. 1976 Meyer 1971

Table 5-2

Periphyton organic accumulation rates in $mg.m^{-2}.day^{-1}$ from June 28, 1972 through December 30, 1976. Values are averages of duplicate samples.

Date	Exposure Period (days)	500.0	501.0	502.0	508.0	504.0	506.0	Mean
23 August 1972	56	NS	NS	30.2	NS	25.2	31.0	28.8
19 October 1972	57	NS	NS	39.1	36.8	33.4	26.2	33.9
14 December 1972	56	NS	NS	3.0	11.1	15.8	0.6	7.6
8 February 1973	56	NS	4.8	2.0	5.1	1.0	2.0	3.0
5 April 1973	56	NS	0.7	0.4	3.6	2.2	4.4	2.3
3 May 1973	56	NS	*	*	17.8	18.8	21.6	19.4
30 May 1973	55	NS	8.6	57.2	132.8	30.2	17.2	49.2
28 June 1973	56	NS	62.4	51.0	109.5	49.4	88.6	72.2
26 July 1973	57	NS	39.0	45.2	103.0	88.6	95.3	74.2
23 August 1973	56	100.2	85.6	66.9	76.5	91.2	103.2	87.3
20 September 1973	56	78.6	81.3	40.0	99.9	67.2	76.6	74.0
17 October 1973	55	61.6	48.4	56.2	120.2	36.8	77.2	66.7
13 November 1973	54	40.9	51.8	*	22.8	18.0	37.3	34.2
5 December 1973	56	11.5	0.4	*	4.1	7.8	14.2	7.6
10 January 1974	58	9.8	2.3	*	6.2	11.4	12.3	8.4
7 February 1974	64	8.9	*	2.9	8.0	5.4	3.9	5.8
7 March 1974	56	20.5	3.6	*	18.6	*	7.2	12.8
5 April 1974	57	6.6	2.1	*	14.5	13.6	30.0	13.4
3 May 1974	57	21.5	4.6	*	12.1	33.5	24.2	19.2
30 May 1974	55	82.4	19.8	*	69.9	38.0	44.3	50.9
27 June 1974	55	145.6	131.5	34.2	65.2	79.1	107.9	93.9
25 July 1974	56	115.6	50.6	*	77.0	101.0	114.1	91.7
29 August 1974	63	109.2	92.6	72.4	70.7	94.4	108.8	91.4
26 September 1974	28	79.7	80.6	64.2	96.7	73.9	89.4	80.8
24 October 1974	28	50.2	52.8	68.6	108.3	42.0	83.3	69.2
26 November 1974	33	44.4	49.4	57.4	25.2	23.2	43.3	40.5
28 January 1975	61	6.2	*	*	13.3	7.6	10.2	9.3
28 January 1975	34	3.4	2.5	*	3.7	4.3	7.2	4.2
3 March 1975	32	1.3	*	1.0	1.3	*	3.6	1.8
1 April 1975	29	3.8	3.8	*	2.4	2.4	2.8	3.0
5 May 1975	33	14.8	5.5	12.5	4.6	10.7	138.6	31.1
3 June 1975	30	73.1	19.8	9.5	15.2	114.3	38.8	45.1
3 July 1975	30	35.6	29.4	35.6	1.5	120.3	87.8	51.7
4 August 1975	32	60.2	49.0	41.6	150.2	106.0	43.6	75.1
3 September 1975	30	74.8	51.6	21.0	112.9	39.4	32.5	55.4
1 October 1975	29	19.9	4.8	3.1	20.2	68.6	33.2	25.0
30 October 1975	29	**	**	**	27.0	**	41.2	34.1
2 December 1975	33	21.8	*	9.7	37.0	24.2	67.8	32.1
31 December 1975	29	3.8	3.4	1.9	6.4	7.5	11.1	5.7
31 January 1976	31	1.1	3.9	2.3	5.2	5.7	**	3.6
1 March 1976	30	9.9	4.7	5.1	4.4	5.5	8.0	6.3
1 April 1976	30	2.9	5.9	4.8	2.6	6.4	61.0	13.9
3 May 1976	32	17.6	12.4	4.4	29.3	22.5	132.5	36.4
1 June 1976	30	59.4	20.9	9.5	20.2	29.3	7.8	24.5
29 June 1976	29	9.1	78.5	18.8	21.8	68.8	155.3	58.7
28 July 1976	29	141.2	105.1	10.8	84.8	39.3	140.2	86.9
30 August 1976	33	58.2	76.1	57.8	91.9	*	89.8	74.8
29 September 1976	30	137.9	70.6	35.2	29.2	67.5	147.0	81.2
29 October 1976	30	77.8	12.4	12.6	*	27.9	108.5	47.8
30 November 1976	32†	14.1	2.0	2.1	3.6	4.7	9.9	6.1
30 December 1976	30	5.2	2.3	3.1	4.0	*	8.0	4.5
Mean		45.1	32.2	26.1	41.0	38.8	53.0	

NS = Sampling not begun
* = Sampler lost
** = Accumulation data lost due to lab accident
† = Station 508.0 this date = 27 days

Table 5-3

Results of two-way analysis of variance of organic accumulation rates, total periphyton density, and major class densities by location and sample period for Lake Keowee, S. C.*

	Transformation	Source	DF	Mean Square	F	Probability
Organic Accumulation Rate	$Sinh^{-1}$	Sampling location	5	0.0960	178.21	<0.01
		Sampling date	50	0.1469	272.70	<0.01
		Station X date	207	0.0078	14.53	<0.01
		Residual	263	0.0005		
Total Periphyton	log	Sampling location	5	0.8864	36.79	<0.01
		Sampling date	17	1.7277	71.71	<0.01
		Station X date	74	0.1601	6.65	<0.01
		Residual	61	0.0241		
Bacillariophyceae	log	Sampling location	5	0.6181	24.92	<0.01
		Sampling date	17	1.3429	54.14	<0.01
		Station X date	74	0.1758	7.09	<0.01
		Residual	61	0.0248		
Chlorophyceae	log	Sampling location	5	2.3868	24.79	<0.01
		Sampling date	17	6.5639	68.18	<0.01
		Station X date	74	0.4360	4.53	<0.01
		Residual	61	0.0963		
Myxophyceae	log	Sampling location	5	1.7241	1.21	0.31
		Sampling date	17	9.6452	6.78	<0.01
		Station X date	74	1.4245	1.00	0.50
		Residual	61	1.4234		

(log) Data transformed by $\log_{10}$
($Sinh^{-1}$) Inverse hyperbolic sin transformation

* Organic accumulation data from June 28, 1972 through December 30, 1976. Density data from July 3, 1975 through December 30, 1976.

Table 5-4

Spearman correlation coefficients and associated probability values for organic accumulation rates, total periphyton densities, major class densities and selected physical-chemical parameters on Lake Keowee, S. C.

	Organic Accumulation Rate	Total Periphyton	Bacillariophyceae	Chlorophyceae	Myxophyceae
Temperature	0.699 (0.001)	0.635 (0.001)	0.550 (0.001)	0.636 (0.001)	0.063 (0.640)
Dissolved Oxygen	-0.560 (0.001)	-0.621 (0.001)	-0.537 (0.001)	-0.614 (0.001)	0.096 (0.479)
Conductivity	0.369 (0.001)	0.588 (0.001)	0.780 (0.001)	0.575 (0.001)	0.160 (0.001)
NO_3	-0.250 (0.001)	-0.297 (0.001)	-0.228 (0.004)	-0.281 (0.001)	-0.136 (0.278)
pH	0.127 (0.006)	0.313 (0.001)	0.258 (0.001)	0.399 (0.001)	0.029 (0.830)
Manganese	0.072 (0.118)	0.499 (0.001)	0.421 (0.001)	0.564 (0.001)	0.170 (0.185)
Alkalinity	0.101 (0.027)	0.116 (0.142)	0.096 (0.228)	0.129 (0.095)	-0.060 (0.646)
Turbidity	-0.296 (0.001)	-0.138 (0.075)	-0.110 (0.166)	-0.020 (0.794)	0.011 (0.932)
Ammonia	0.001 (0.998)	0.156 (0.118)	0.231 (0.024)	0.076 (0.440)	0.303 (0.041)
Ortho-phosphate	-0.121 (0.011)	0.078 (0.347)	0.115 (0.176)	0.077 (0.344)	-0.029 (0.823)
Total phosphate	-0.065 (0.168)	0.146 (0.063)	0.160 (0.045)	0.116 (0.135)	-0.117 (0.372)
Chloride	-0.076 (0.094)	-0.111 (0.152)	-0.158 (0.042)	0.003 (0.968)	0.142 (0.252)
Iron	0.119 (0.010)	0.029 (0.711)	0.014 (0.850)	0.048 (0.534)	-0.228 (0.075)
Silica	-0.154 (0.001)	-0.033 (0.673)	-0.027 (0.739)	-0.008 (0.922)	0.040 (0.755)
Total Nitrogen	0.086 (0.060)	0.059 (0.448)	0.070 (0.379)	0.055 (0.476)	0.006 (0.961)
Nitrogen-Phosphorus Ratio	0.076 (0.108)	0.181 (0.169)	0.084 (0.305)	0.091 (0.285)	0.153 (0.068)
Organic Accumulation Rate		0.737 (0.001)	0.705 (0.001)	0.640 (0.001)	0.170 (0.201)

Table 5-5

Distribution of periphytic taxa among algal classes in Lake Keowee, S. C. from July 3, 1975 through December 30, 1976.

Taxon	Genus	Species	Variety
Bacillariophyceae	29	144	61
Chlorophyceae	16	38	5
Myxophyceae	5	10	0
Dinophyceae	2	5	0
Cryptophyceae	2	4	0
Chrysophyceae	2	2	0
Euglenophyceae	1	1	0
Totals	57	204	66

Table 5-6

Rank of class density, based on index of dominance and average percent composition of periphytic algal classes in Lake Keowee, S. C. from July 3, 1975 through December 31, 1976.

TAXON	Monthly Dominance Rank 1975 J	A	S	O	N	D	1976 J	F	M	A	M	J	J	A	S	O	N	D	Overall Dominance Index (x 10^{-3})	Overall Rank	Average Percent Composition
Bacillariophyceae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2680.80	1	67.4
Chlorophyceae	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	207.60	2	30.5
Myxophyceae	3			3	3	3			3	3	3	3	3	3	3	3	4		1.00	3	1.8
Chrysophyceae										4		4	4	4	4	4			0.11	4	0.2
Cryptophyceae								4				5	5	5	5	5	3	3	0.04	5	<0.1
Dinophyceae								3			4	6	7	6	6			4	0.01	6	<0.1
Euglenophyceae												7	6				5	5	<0.01	7	<0.1

* Blanks indicate taxa not present during a given period.

Table 5-7

Total periphyton densities in units$\cdot cm^{-2}$ from July 3, 1975 through December 30, 1976 in Lake Keowee, S. C.

Date	Exposure Period (days)	Locations						
		500.0	501.0	502.0	508.0	504.0	506.0	Mean
4 August 1976	32	275,900	204,500	202,700	402,400	221,600	107,900	235,800
3 September 1975	30	153,400	171,600	30,100	150,500	168,600	87,810	127,000
1 October 1975	29	34,200	117,800	68,000	555,800	31,420	112,500	153,300
30 October 1975	29	28,200	131,100	94,210	266,200	259,400	150,900	155,000
2 December 1975	33	150,900	*	58,920	248,000	161,900	199,200	163,800
31 December 1975	29	50,000	31,600	11,670	54,140	75,160	42,540	44,180
31 January 1976	31	2,210	7,740	11,740	115,900	29,840	12,430	29,980
1 March 1976	30	2,650	3,636	10,050	26,500	14,000	23,930	13,460
1 April 1976	30	17,500	19,060	16,040	36,460	46,260	62,500	32,970
3 May 1976	32	107,100	3,870	22,380	86,990	157,500	106,600	80,740
1 June 1976	30	79,100	26,580	25,640	165,900	13,710	17,710	54,780
29 June 1976	29	68,500	54,960	103,300	53,730	28,850	46,980	59,390
28 July 1976	29	54,400	67,740	77,380	233,500	61,570	136,200	105,130
30 August 1976	33	134,700	154,600	146,000	639,900	*	125,600	240,000
29 September 1976	30	344,300	175,300	49,730	136,500	107,500	165,100	163,100
29 October 1976	30	156,300	26,730	65,760	*	106,240	258,900	122,800
30 November 1976	32†	50,240	9,380	7,620	20,610	27,410	41,970	26,200
30 December 1976	30	9,410	2,940	2,450	7,640	*	13,500	7,187
Mean		95,510	71,130	55,760	188,300	94,400	95,130	

* Sampler missing

† Location 508.0 this date = 27 days

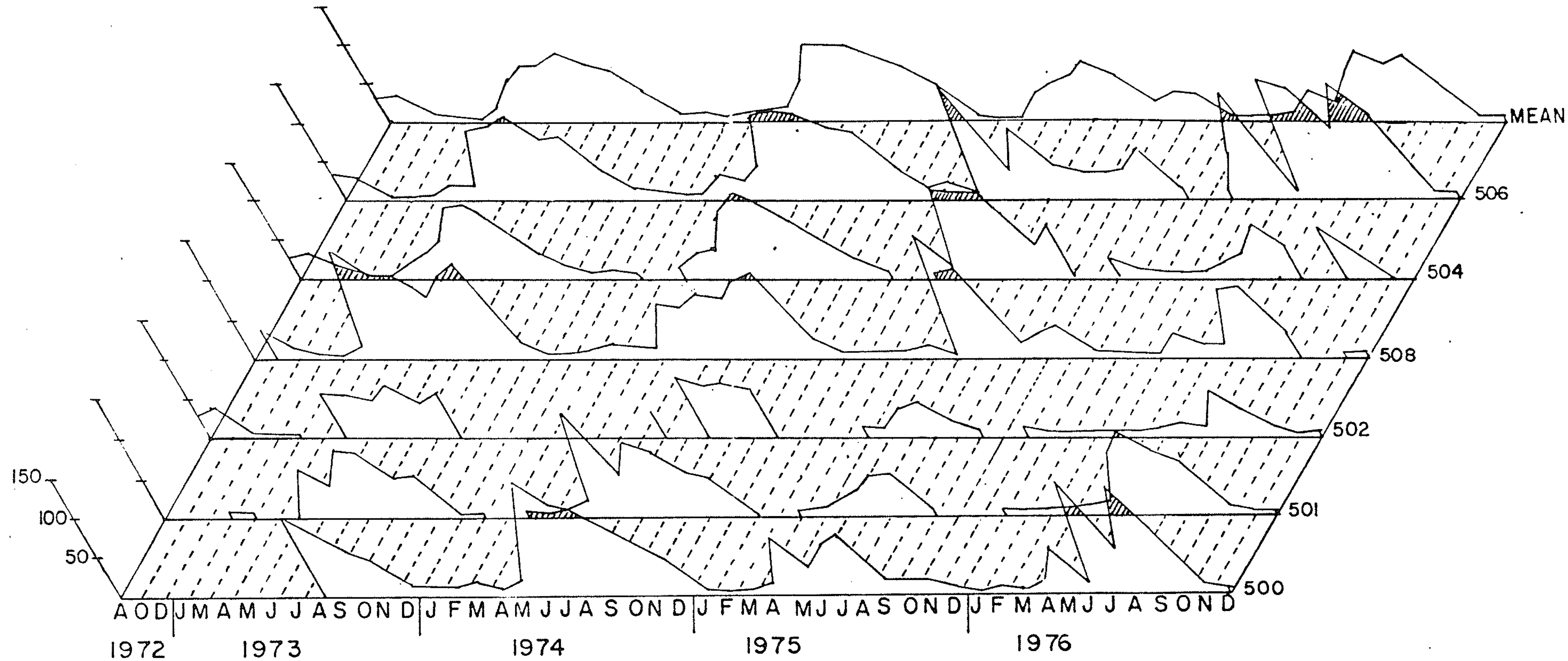


Figure 5-1

Periphyton organic accumulation rates in mg·m^{-2}·day^{-1} for locations in Lake Keowee, S. C. from June 28, 1972 through December 30, 1976.

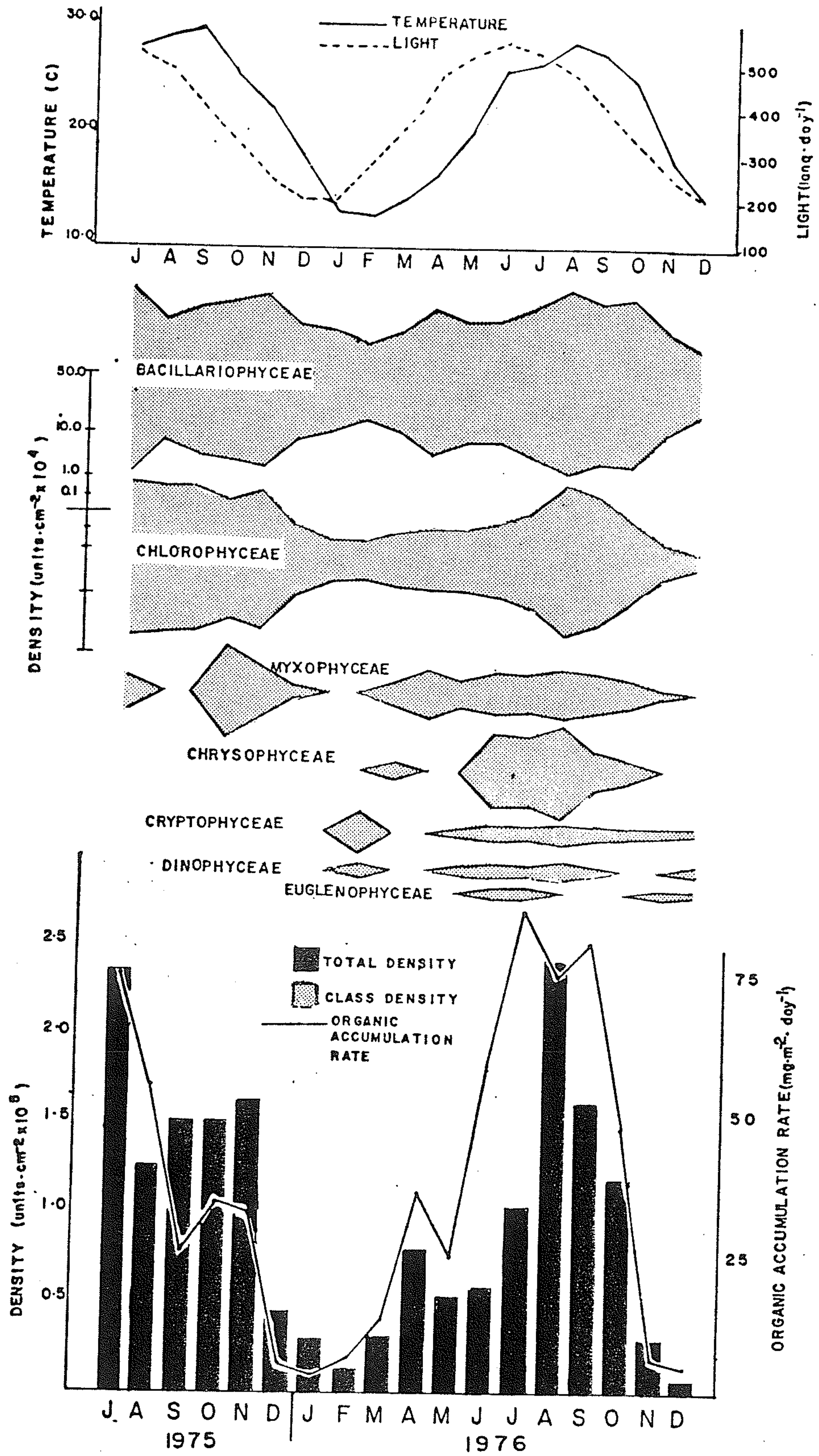


Figure 5-2

Comparisons of mean values for organic accumulation rate, total periphyton density, major class densities, temperatures and solar radiation for locations in Lake Keowee, S. C. from July 3, 1975 through December 30, 1976.

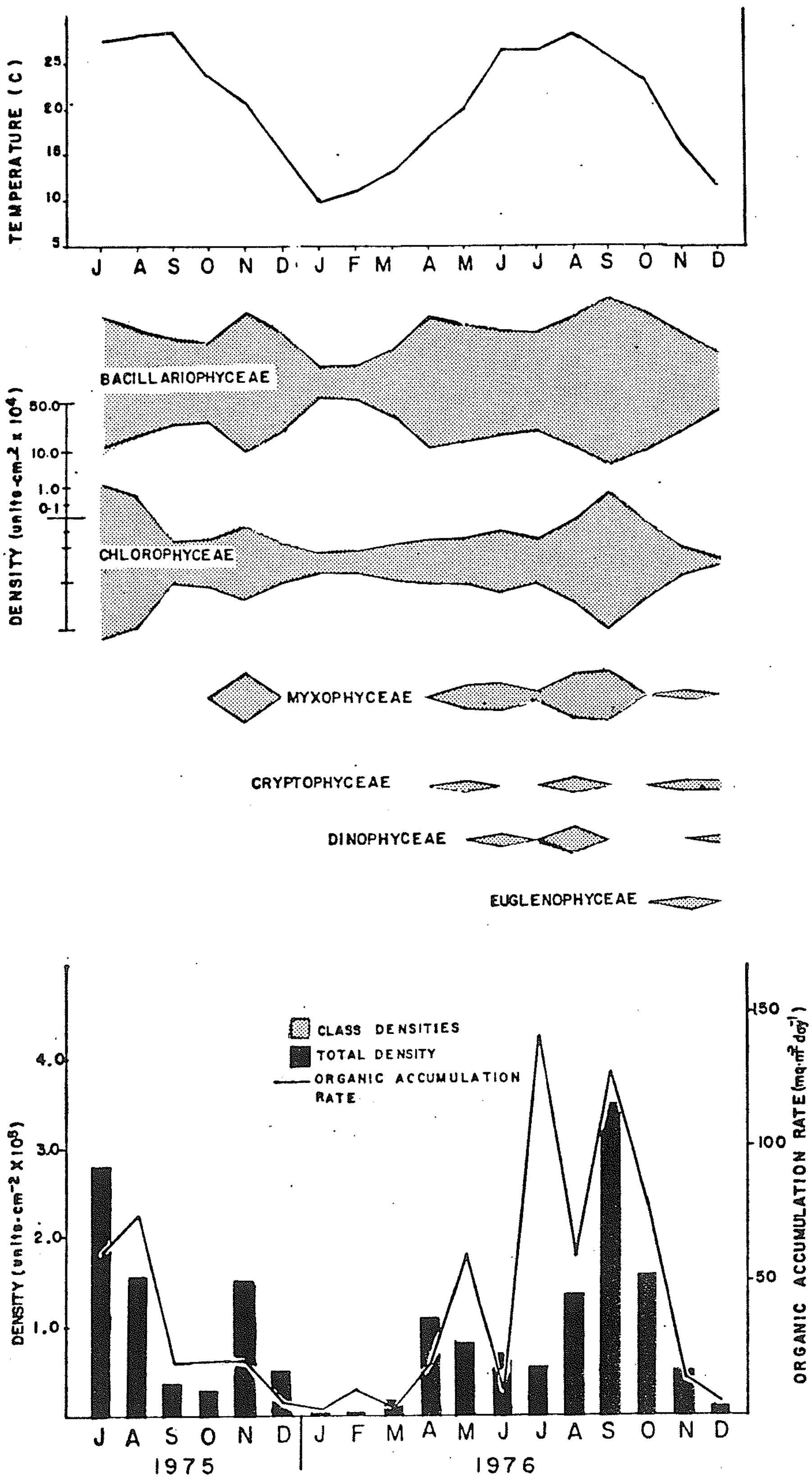


Figure 5-3

Comparisons of organic accumulation rate, total periphyton density, major class densities and temperature at Location 500.0 in Lake Keowee, S. C. from July 3, 1975 through December 30, 1976.

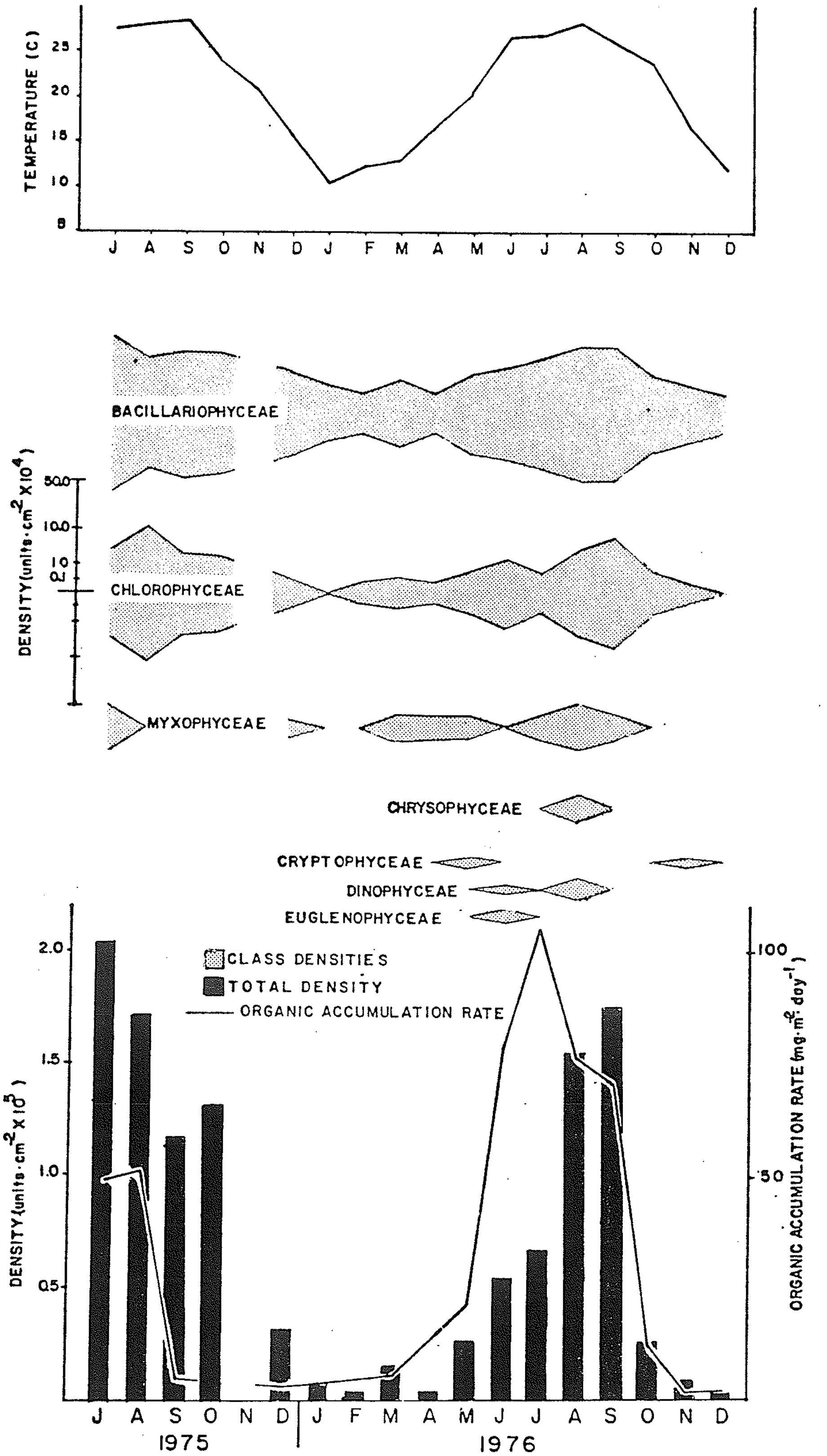


Figure 5-4

Comparisons of organic accumulation rate, total periphyton density, major class density and temperature at Location 501.0 in Lake Keowee, S. C. from July 3, 1975 through December 30, 1976.

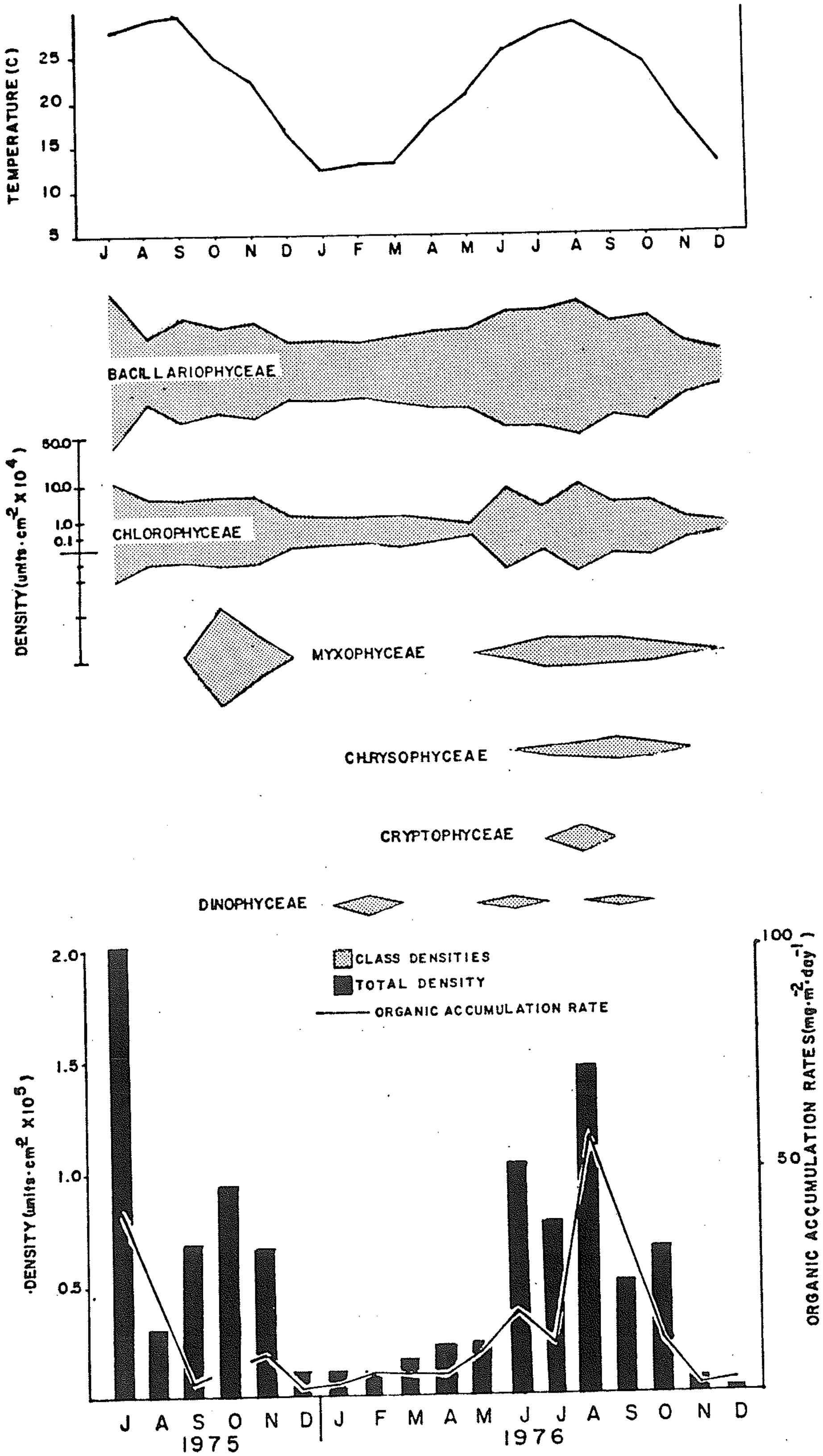


Figure 5-5

Comparisons of organic accumulation rate, total periphyton density, major class densities and temperature at Location 502.0 in Lake Keowee, S. C. from July 3, 1975 through December 30, 1976.

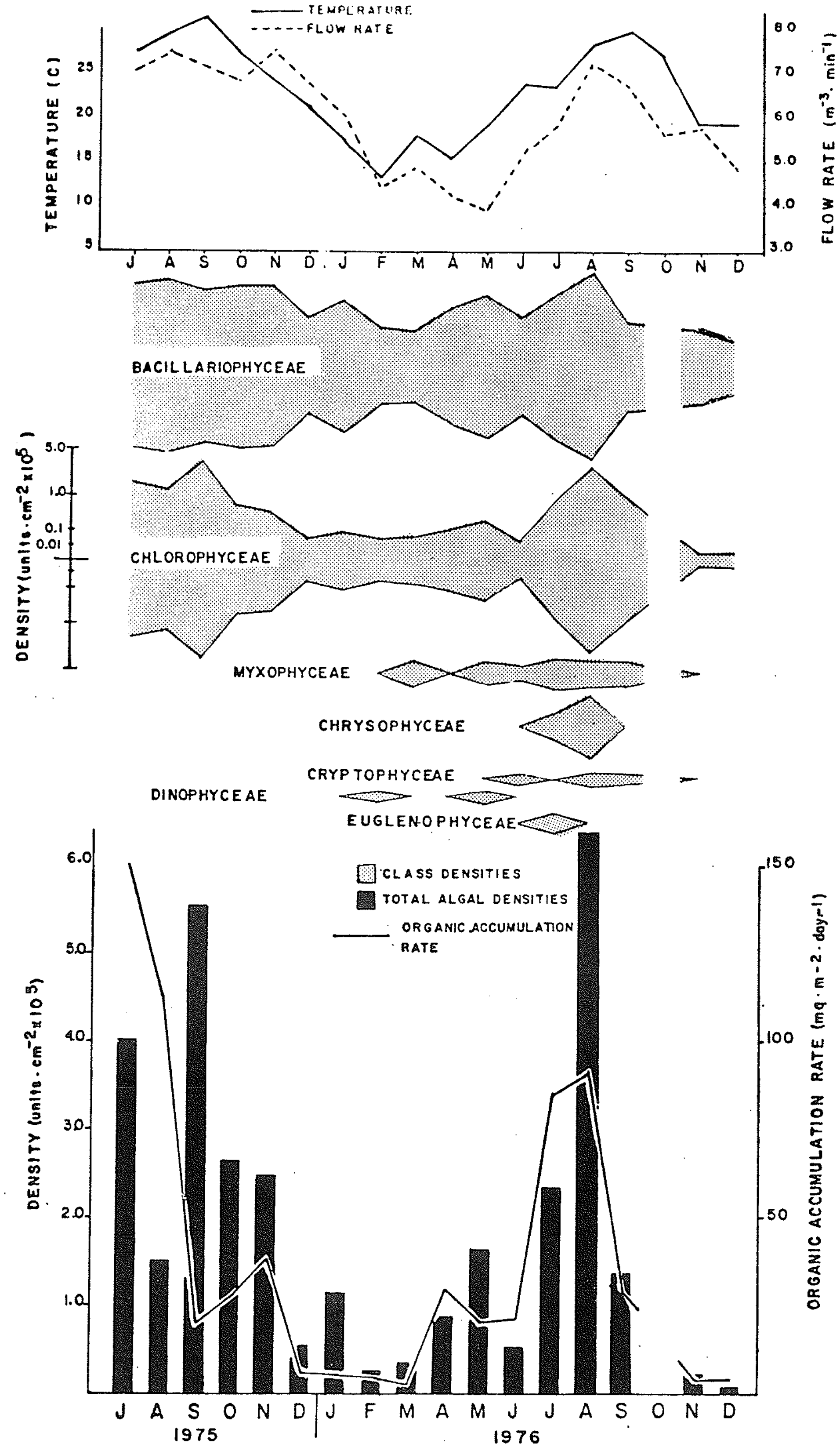


Figure 5-6

Comparisons of organic accumulation rate, total periphyton density, major class densities, temperature and flow rate at Location 508.0 in Lake Keowee, S. C. from July 3, 1975 through December 30, 1976.

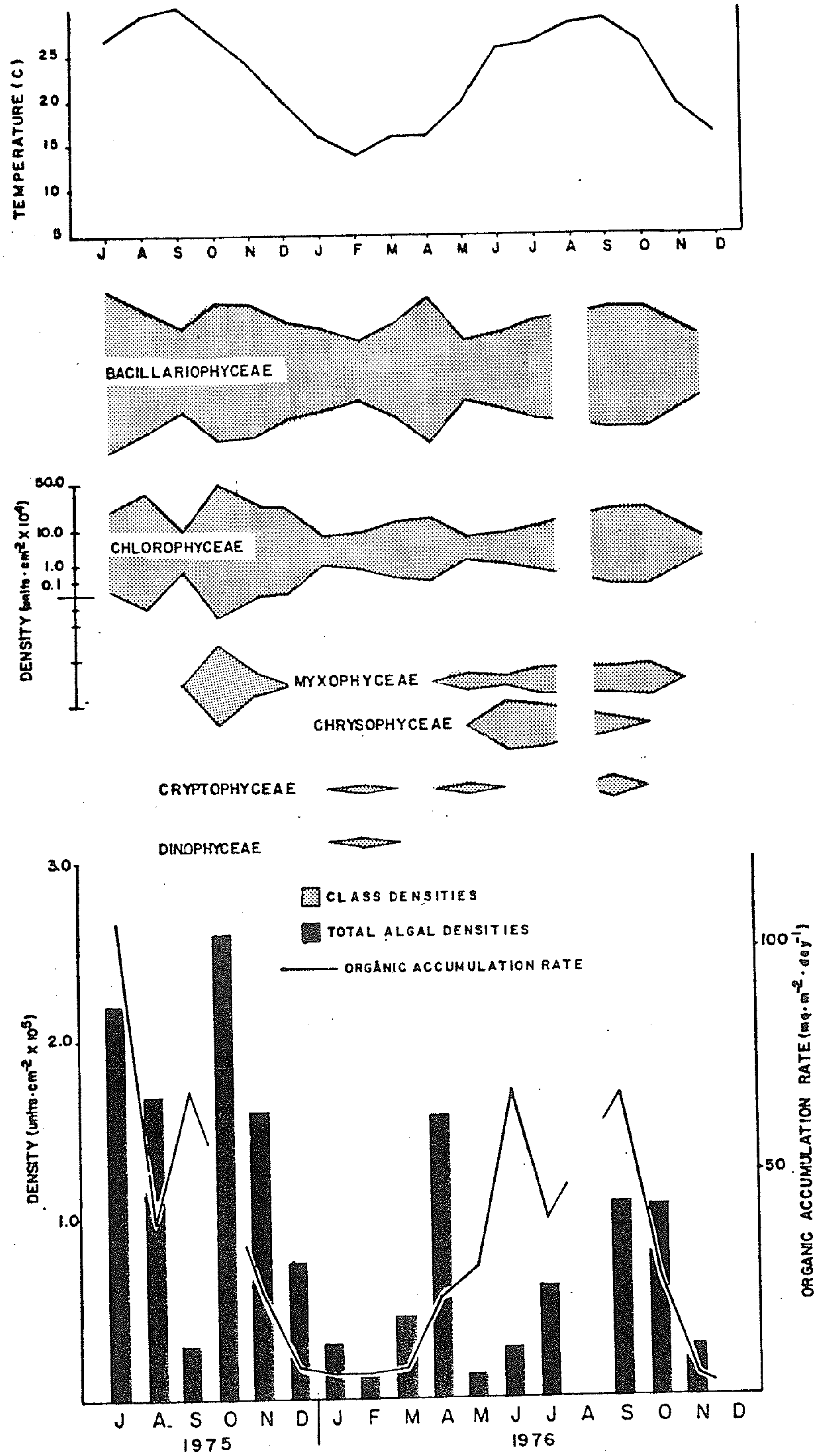


Figure 5-7

Comparisons of organic accumulation rate, total periphyton density, major class densities and temperature at Location 504.0 in Lake Keowee, S. C. from July 3, 1975 through December 30, 1976.

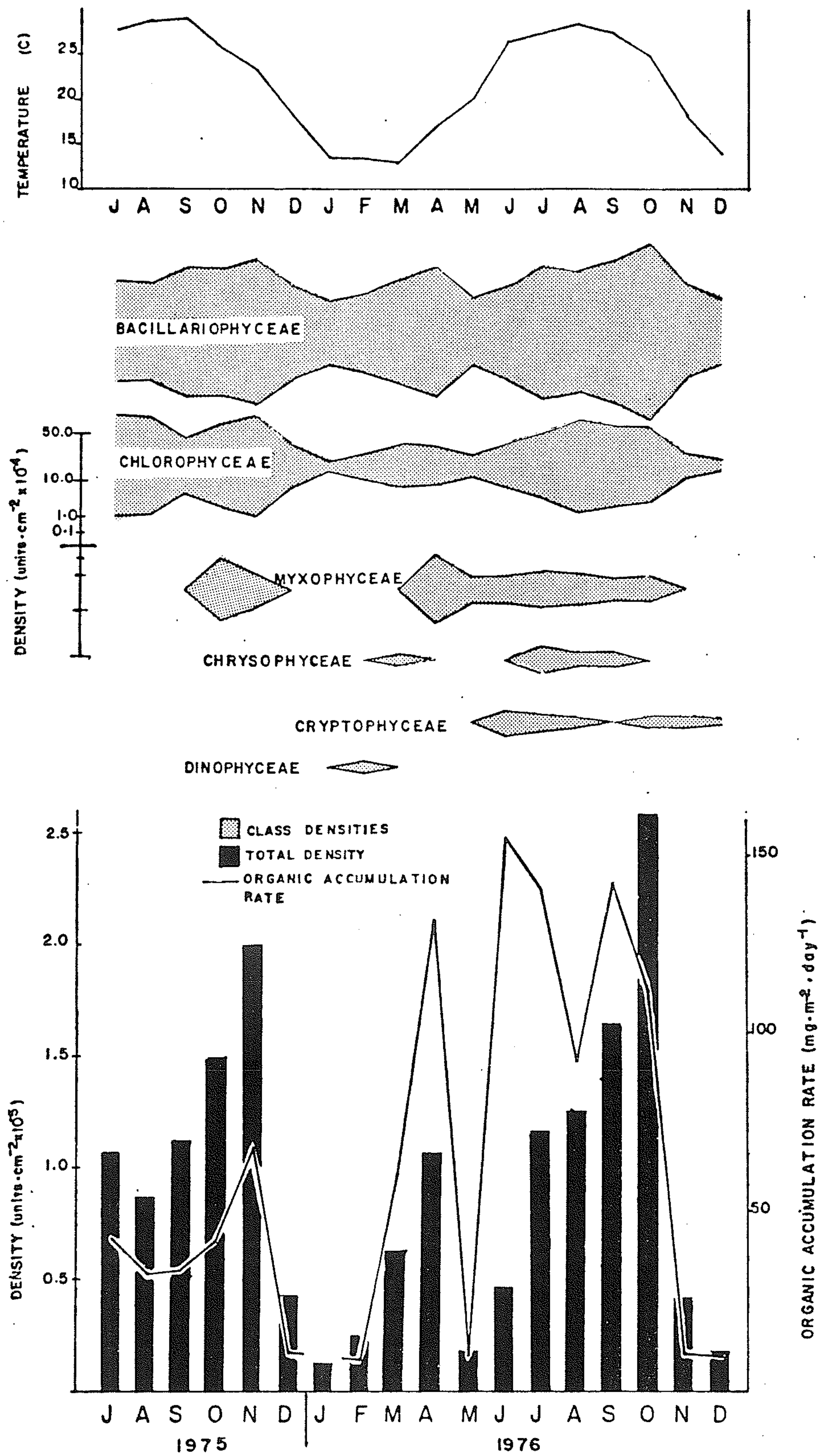
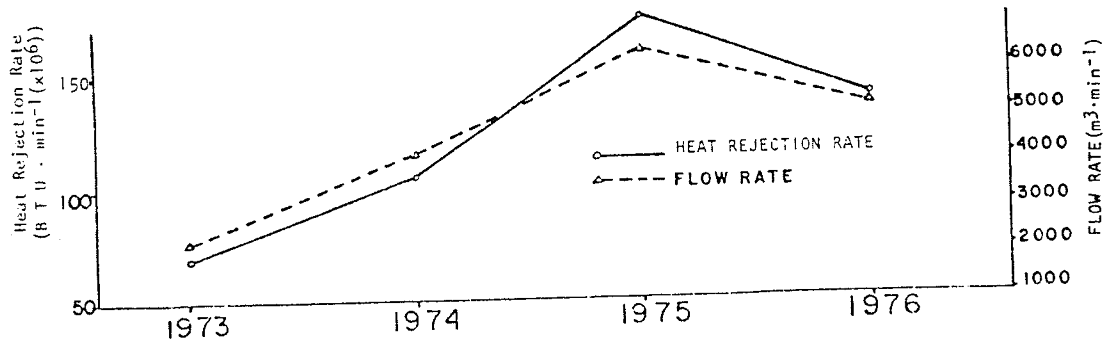


Figure 5-8

Comparisons of organic accumulation rate, total periphyton density, major class densities and temperature at Location 506.0 in Lake Keowee, S. C. from July 3, 1975 through December 30, 1976.



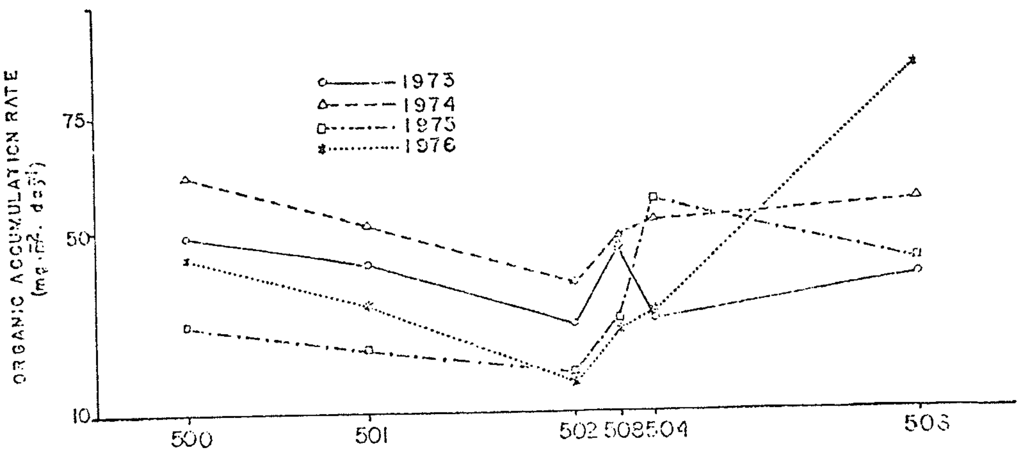


Figure 5-9

Yearly integrated organic accumulation averages for each location in Lake Keowee and integrated BTU and flow rate means at Oconee Nuclear Station from December 1972 through December 1976.

Chapter 6 ZOOPLANKTON

INTRODUCTION

Zooplankton are an essential component in the food chain of reservoirs. They represent the trophic link between the autotrophic phytoplankton and secondary consumers (benthos, fish). Exposure of zooplankton to heated effluents of steam-electric power stations, and the entrainment of these organisms through the Condenser Cooling Water (CCW) systems, may affect zooplankton populations in the receiving waters, and could ultimately affect other trophic levels of the aquatic ecosystem (Levin et al. 1970).

Bunting (1974), Goss and Bunting (1976), Heinle (1969), and Jensen et al. (1969) noted that elevated temperatures affected zooplankton metabolism, development, growth, reproduction, and survival. The degree to which biological processes are affected by temperature depends on several factors, including temperature range, exposure time, acclimation temperature, stage in life history, and interactions of temperature with other environmental variables. Metabolic and development rates usually increase with increased temperature. However, when an upper extreme temperature for a particular species is attained there is generally a reversal in metabolic rate; it is usually not far beyond this temperature that the death of the zooplankter is imminent (Goss and Bunting, 1976). Coutant (1970), Davies and Jensen (1975), Harmsworth (1973), and Heinle (1969) concluded that power plants could alter the species composition of the zooplankton community in receiving waters by eliminating species which are particularly susceptible to mechanical damage and/or thermal stress. Davies and Jensen (1975) discerned that interactions of ambient temperature, temperature rise (ΔT) and mechanical stress were important factors affecting the motility of entrained zooplankton. For organisms that survive the immediate shock of entrainment, there remains the possibility of delayed mortality or impaired reproductive potential (Carpenter et al. 1974, Restaino et al. 1974). Table 6-1 presents a summary of entrainment studies on zooplankton from various freshwater ecosystems.

The construction and operation of Oconee Nuclear Station (ONS) necessitated a study of the zooplankton of Lake Keowee, South Carolina (Duke Power Company 1973a). A study was initiated in July 1973 to determine the effects of ONS on the receiving water zooplankton populations. Density and taxonomic composition of the zooplankton was estimated in areas within and outside the ONS heated effluent. A study was initiated in September 1973 to estimate the effect of passage through the CCW System on the zooplankton.

MATERIALS AND METHODS

ENTRAINMENT

The Technical Specification (Specification 1.5, Duke Power Company 1973a) required that samples be collected at least six times per year. Collections were to be made using either plankton nets or pumps at the CCW System intake and at the heated water discharge before it entered the receiving waters. Samples were to be analyzed for types, quantities, and survival of the various planktonic groups. Sampling would be such as to encompass the range of temperature rises across the condenser. The program described below met or exceeded requirements set forth in the Technical Specifications.

Field Procedures

Samples for immotility analysis were collected on 20 occasions from September 1973 through November 1976 (Table 6-2). The first three collections (September 1973, November 1973, and January 1974) will not be discussed or included in data analysis as they were taken while techniques were being refined. For each entrainment sample approximately 2,000 liters of condenser cooling water were filtered from taps at the Unit I precondenser and postcondenser water boxes into barrels calibrated to 98.4 liters (26 gal.). The flow rate was determined (between 49.2 and 98.4 ℓ/min.) and recorded, then a 76 μm mesh, 30 cm (mouth diameter) plankton net was suspended in each of the two barrels. A quantity of water was filtered and filtering time recorded (30-45 min.). The net contents were then transferred to one liter incubation bottles with netted windows of 76 μm mesh netting. The bottles were placed in an insulated container with water from the same collection location and of the same temperature as the filtered samples. The netted windows on the incubation bottles allowed constant water exchange and were a means of concentrating the samples for immotility determination (Davies and Jensen 1974). The samples were then transferred to the laboratory.

Laboratory Procedures

Immotility was assessed within one hour after collection. Additional assessments were made at 6 and 24 hours after collection. However, counts at 6 and 24 hours were discontinued in July 1974 due to the stress of crowding during incubation bottle storage and the difficulty of approximating temperature decay rates.

For immotility assessment, the sample in the incubation bottle was concentrated to approximately 100 ml and an 0.8 ml aliquot was placed in a clean Sedgwick-Rafter counting cell. Strip counts of the entire cell were performed at 100X on a compound microscope. The number and species of immotile organisms were recorded. The contents of the cell were then killed by adding 0.2 ml of 10% formalin solution. All the dead organisms were then enumerated (Davies and Jensen 1974).

The percentage of immotile organisms was determined as follows:

$$\text{Percent Immotile} = \frac{\text{no. immotile organisms in first count}}{\text{total no. organisms in second count}} \times 100$$

Corrected Percent Immotile was calculated as follows:

$$\text{Corrected Percent Immotile} = \text{CPI} = \frac{P-C}{100-C} \times 100$$

where:

P = Postcondenser or Discharge Percent Immotile
C = Precondenser or Intake Percent Immotile

The CPI calculation was designed to discern the effect of passage through the condenser system by correcting for immotility prior to passage through the CCW System and immotility resulting from sampling technique. The CPI calculation was adapted after Abbots P (Finney 1962). Negative CPI values were assumed to be zero.

Rotifer immotility analyses were discontinued in 1975. The rationale for discontinuing rotifer immotility analyses were the high turnover rates of rotifer populations (Edmondson 1960, 1965) and the lack of discernible entrainment entrainment effects on them (Duke Power Company 1974b, 1975a).

A comparative study between compound microscope and dissecting microscope methods of immotility assessment (Duke Power Company 1974b) resulted in the adoption of the dissecting scope method for immotility assessment of the crustacean zooplankton. The dissecting microscope method allowed more accurate assessment of immotility because live organisms could be prodded with a dissecting needle in an attempt to evoke a motile response. Adopting the dissecting scope method resulted in the following: 1) More organisms per subsample were processed (approximately 200 per subsample instead of 100 per count). 2) Morning and afternoon sample replication was initiated at pre- and postcondenser sample locations beginning in November 1974.

Intake and discharge sampling locations were adopted in January 1975. Live samples were taken from the intake canal adjacent to the Unit I intake structure and at the discharge structure. A vertical haul from bottom to surface was performed at both intake and discharge using a 0.5 m diameter 76 μm mesh plankton net. Samples were retained and immotility determined by the same methods used for pre- and postcondenser samples. In January 1976, morning and afternoon replication was begun at the intake and discharge. A calculation was performed to indicate net effect of ONS on the zooplankton. Net entrainment effect was arrived at by taking the difference between discharge percent immotile and intake percent immotile.

To aid in determining the effect of passage through the CCW System on the zooplankton, physical damage analysis was implemented in May 1975. Entrainment samples were retained and preserved for the analysis. The samples were processed using a stereo dissecting microscope at 20 to 80 magnification. A minimum of 200 organisms per sample were examined and each organism was classified as damaged or non-damaged. Damaged organisms were those showing any obvious physical injury (e.g. torn carapace, missing or broken appendages). Percent damage and corrected percent damage values were determined by the same methods used for immotility data.

A special study was performed in April 1976 in addition to the regular sampling program. The purpose of this study was to determine if there were changes in Crustacea immotility and physical damage as Unit I was taken from zero power to near full power. In conjunction with this study, zooplankton immotility at Location 502.0 (lakeside of the skimmer wall) was determined and compared to intake canal immotility (Duke Power Company 1976).

Data Analyses

Spearman's rank correlation coefficient (Conover 1971), a non-parametric measure of association was calculated for C.P.I., percent immotility,

s the condenser. The program described below met
s set forth in the Technical Specifications.

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.976 (Table 6-2). The first three collections
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lysis as they were taken while techniques were being
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barrels calibrated to 98.4 liters (26 gal.). The flow
tween 49.2 and 98.4 ℓ/min.) and recorded, then a 76 μm
neter) plankton net was suspended in each of the two
f water was filtered and filtering time recorded
contents were then transferred to one liter incubation
ndows of 76 μm mesh netting. The bottles were
container with water from the same collection location
ature as the filtered samples. The netted windows on
allowed constant water exchange and were a means of
les for immotility determination (Davies and Jensen 1974).
transferred to the laboratory.

d within one hour after collection. Additional assess-
nd 24 hours after collection. However, counts at 6 and
nued in July 1974 due to the stress of crowding during
age and the difficulty of approximating temperature

ent, the sample in the incubation bottle was concentrated
l and an 0.8 ml aliquot was placed in a clean Sedgwick-
Strip counts of the entire cell were performed at 100X
pe. The number and species of immotile organisms were
s of the cell were then killed by adding 0.2 ml of 10%
l the dead organisms were then enumerated (Davies and

otile organisms was determined as follows:

$$= \frac{\text{no. immotile organisms in first count}}{\text{total no. organisms in second count}} \times 100$$

otile was calculated as follows:

$$\text{t Immotile} = \text{CPI} = \frac{P-C}{100-C} \times 100$$

ndenser or Discharge Percent Immotile
denser or Intake Percent Immotile

ious physical-
cedure was performed
tors of zooplankton
ient variable was
at the 0.3 m depth
mer wall). These

s of variance, was
a were tested for
tween locations.

culated using pro-

Keowee from July
ted during the study
the use of more
nd the addition of
scribed below ex-
any 1973a).

y 1973 through July
rbel 1970) with
mples were collected
ing a 0.5 m mouth

han 15 m, tows were
ate 10 m to surface

ocation 502.0 using a
6 μm mesh net.
at 2 m depth

dded as a relaxant
5 minutes, samples
aney and Hall 1972)

o obtain a density
d enumerated per
5 ml) randomly with-

drawn with a pipette. Whole sample enumerations were performed on the diel samples.

Rotifers were enumerated in a 1-ml Sedgwick-Rafter counting cell using a compound microscope at 79 to 100 magnification. Microcrustaceans (copepods and cladocerans) were enumerated in a Ward zooplankton counting wheel using a dissecting microscope at 20 to 80 magnification. Organisms that could not be positively identified in a subsample were later removed from the counting chamber and examined with a compound microscope under higher magnifications (100 to 400X). Major taxonomic references included Brooks (1957), Edmondson (1959), Marsh (1910), Pennak (1953), Voight (1956), and Yeatman (1944). Identifications were periodically confirmed by taxonomic consultants, D. L. Bunting, S. I. Dodson, D. G. Frey, M. A. Hegyi, and H. C. Yeatman.

Data Analyses

The initial five bimonthly collections (July 1973 through March 1974) were considered a period for resolving field and laboratory procedural and technical problems. These data were not included in the data analyses and are not discussed. Standing crop data from May 1974 through December 1976 were analyzed and are discussed. Sampling locations included in the data analyses are categorized in Table 6-8.

For statistical analyses, sampling dates were divided into stratified and destratified thermal periods. Division was based on changes in vertical distribution of zooplankton indicated from bottom to surface and 10 m to surface density comparisons lakeside of the skimmer wall at Location 502.0 (Figure 6-16). A thermal gradient greater than 3 C existed from near surface to 20 m (approximate depth of skimmer wall opening at full pond) at Location 502.0 for months categorized as stratified. During destratified months the thermal gradient at Location 502.0 was less than or equal to 3 C.

Standing crops from 10 m to surface for major taxonomic categories (Copepoda, Cladocera, Rotifera, and Total Zooplankton) were analyzed statistically as follows: 1) Numbers per liter data for stratified and destratified thermal periods of 1974, 1975, and 1976 were tested for homogeniety of variances using the Levene Test (Keppel 1973) but did not meet the assumption of homoscedasticity. 2) Data were analyzed for location and year effects using the Friedman Test. Because of the complete block design of the Friedman Test, certain sampling dates and locations were omitted from the statistical analyses. These were the dates August 1974, July 1975, and March 1976, and Locations 501.0 and 504.0. Statistical treatment of data using the Friedman Test is summarized in Table 6-9. 3) Data groups that yielded significant results ($P \leq 0.05$) were subjected to a nonparametric multiple range test similar to the Student Neuman-Keul Test (Zar 1974). This test was not sensitive enough to detect differences ($P \leq 0.05$) among the ranked locations and was therefore abandoned. 4) As an alternative, spatial differences were analyzed graphically.

Because the bottom depth differed greatly among sampling locations, no statistical treatment of data was performed on bottom to surface data. Diel data were not statistically analyzed.

RESULTS AND DISCUSSION

ENTRAINMENT

On the study dates, the lowest intake (10.1 C) and discharge temperatures (15.0 C) occurred in the winter (Figure 6-1). Highest intake-discharge ΔT (12.0 C°) was encountered during winter (Figure 6-2) when the thermal gradient was least pronounced. The greatest intake (26.5 C) and discharge (32.2 C) temperatures were encountered during periods of greatest thermal gradient. Water temperatures at the Unit I precondenser and postcondenser were very similar to those temperatures at intake and discharge. Temperatures at the precondenser ranged from 10.0 C to 26.1 C and at the postcondenser from 10.0 C to 35.6 C. The ΔT's across the Unit I condenser ranged from 0.0 C° to 12.0 C°.

Due to large seasonal variation of species densities and occurrences, entrainment data will be discussed primarily in terms of the major taxonomic categories of Cladocera, Copepoda, and the total Crustacea. Detailed analyses of immotility for individual species (by sample date and location) have been presented (Duke Power Company 1974a, b; 1975a, b; 1976).

The Lake Keowee zooplankton was numerically dominated by rotifers and the smaller forms of the Copepoda (i.e. nauplii, copepodids) with the Cladocera seldom dominant or relatively abundant. A discussion of and rationale for discontinuing the investigation of Rotifera immotility has been presented (Duke Power Company 1974b, 1975a).

Immotility Analyses

For the purposes of this study, immotility was defined as the inability of an organism to exhibit any detectable movement. Immotility was used as an indication of mortality, but percent mortality was probably less than the percent immotile. Any movement of an organism was considered an indication of life. Jensen et al. (1969) indicated that although a shocked or twitching organism may be close to death there is always the possibility of recovery. Coker (1934) noted that some copepods assumed a state of dormancy when exposed to temperature increases and revived hours or even days after being returned to ambient temperature.

An evident seasonal trend in immotility for the Cladocera, Copepoda, and total Crustacea, is illustrated in Figures 6-3, 6-4, and 6-5, respectively. Major immotility peaks occurred during the summer months as contrasted with comparatively low immotility during the winter. Although the data depicts an obvious seasonal trend, the results of Friedman's test by thermal period (thermal periods are shown in Table 6-9) were not significant for the major taxa. Results of Spearman's rank order correlation coefficients (rho) were significant ($P \leq 0.05$) for percent immotilities of the major taxonomic categories at the postcondenser and discharge sites versus the postcondenser and discharge temperatures, respectively. However, highly significant ($P \leq 0.001$) rho values were found for percent immotility of these same taxonomic categories at the discharge, versus the intake temperatures and precondenser temperatures (Table 6-3).

These data suggest that at higher acclimation temperatures (intake canal), the zooplankton were less tolerant of thermal increases and condenser passage, which is contradictory to findings of Coker (1934). Coker found individuals acclimated at high temperature levels may endure higher temperatures than organisms acclimated at lower temperature levels. Bunting (1974) recognized the relationship of acclimation temperature to thermal tolerance and stated that zooplankters acclimated at high or low temperatures may be less tolerant than those acclimated at intermediate temperature levels.

Generally, the final temperatures to which the zooplankton were exposed during this study, were not lethal to most microcrustaceans (Goss and Bunting 1976, Bunting 1974, Brown 1929). Therefore, if immotility resulting from condenser passage were a function of or related to ambient temperature, it is hypothesized to be an indirect relationship and not a direct physiological cause of immotility. The periods of highest intake temperatures corresponded to a well defined thermal gradient at the deeper locations in the reservoir. Standing crop densities during these periods were shown to be considerably greater in the upper 10 m than in the deeper water (see zooplankton receiving water section). The reasons for this distribution pattern are complex; however, temperature, food concentration, and light intensity optima were probably the primary factors affecting the vertical distribution. Zooplankton in the deeper strata may exist there as a result of the inability to maintain vertical position due to injury, age, or other stresses. Those animals in the deeper water (>20 m) at Location 502.0 would likely be entrained by ONS.

In an attempt to further investigate this phenomena, a comparison was performed on percent immotility data during April 1976 between Location 502.0 (lakeside of the skimmer wall) bottom to surface (b-s) and 10 m to surface (10-s) and the Location 509.5 10-s (intake canal). These data are shown in Figure 6-6. The total Crustacea percent immotility at Location 502.0 was slightly greater in the b-s than in the 10-s samples (4% and 2%, respectively). The percent immotility was probably greater than 4% in the water column below 10 m because the b-s percent immotility was biased by the inclusion of the 10-s organisms with b-s organisms. This hypothesis is supported by the comparatively high percent immotility for total Crustacea in the intake canal (7-19%) over the four collecting dates compared to the 2% immotility lakeside of the skimmer wall (10-s). As the reservoir developed a thermal gradient during the summer months, the already stressed or perhaps dead zooplankton were entrained resulting in substantially greater percent immotility values during the summer months.

Highest CPI values (Figure 6-7) for precondenser-postcondenser and intake-discharge occurred during months with substantial thermal gradation and highest intake temperatures. The relationship of immotility and ambient temperature was evident with total Crustacea CPI from the intake-discharge being significantly correlated with intake temperature as well as discharge temperature and thermal gradient (Table 6-4). Other significant correlations were found between percent immotility, CPI, and various physical or chemical parameters, but these were considered to be an indirect association with temperature (e.g. D.O. and flow rate).

Friedman's ANOVA indicated no significant differences (P = 0.05) during either of the thermal periods for percent immotile between the precondenser and postcondenser or between the intake and discharge for any of the major taxonomic categories. A seasonal trend (winter versus summer) was evident when the net entrainment effect was assessed (discharge percent immotile minus intake percent immotile). The maximum net entrainment effect on the total Crustacea (32.6%) occurred in July 1975 and the minimum net effect (0.0) occurred during several winter and spring months. Table 6-6 presents percent immotile at intake and discharge over the entire study period. The net effect for the entire study period (total Crustacea = 2.2%) appeared to be inconsequential.

The 1976 immotility study performed as Unit I was taken from zero power to near full power yielded no significant correlations between percent immotile and selected physical-chemical parameters. Although there were no significant correlations, some general trends were noted. Cladocera and total Crustacea CPI values for precondenser-postcondenser generally increased (Figure 6-8) as Unit I power levels and ΔT's increased (Figure 6-9). Copepoda CPI showed no clear trend as power levels at Unit I increased. It appeared that the Cladocera were more susceptible to the stresses of entrainment (e.g. temperature, flow rate, mechanical abrasion) than were the Copepoda. There were no clear trends exhibited by intake-discharge data during this April 1976 study.

Damage Analyses

With few exceptions, percent damage increased from the intake to the precondenser, postcondenser, and discharge sites (Figures 6-10, 6-11, 6-12). Percent damage data for Cladocera, Copepoda, and total Crustacea exhibited the same seasonal trends as percent immotility. Highest percent damage was found during months when the thermal gradient was most pronounced (June through September) and damage was lowest during destratified conditions.

Friedman's ANOVA results indicated no significant differences ($P \leq 0.05$) for percent damage between the intake and discharge, precondenser and postcondenser, thermal periods or among months.

Spearman's correlations indicated that Cladocera and total Crustacea percent damaged at the intake were significantly correlated ($P \leq 0.05$) with thermal gradient at Location 502.0 (Table 6-5). Little damage was noted at the intake, with the Cladocera appearing to be more susceptible to entrainment damage than the Copepoda. Total Crustacea percent damage at precondenser, postcondenser, and discharge were significantly correlated with intake temperature. Because of the relationship of many of these parameters to each other (e.g. intake temperature, D.O., flow rate), it was virtually impossible to isolate a single factor as being responsible for an organism's susceptibility to damage.

Percent damage values for the open lake (Location 502, April 7, 1976) are presented in Figure 6-6 in conjunction with intake percent damage values for April 3, 6, 8, and 14. At Location 502, b-s percent damage was greater than 10-s percent damage. Percent damage in the intake (Location 509.5) was variable, but was generally higher than damage at Location 502 b-s. This was the same basic pattern as was reported for the immotility analyses. No trends in percent damage were apparent at precondenser, postcondenser, or discharge during the increasing power level study.

RECEIVING WATER

The zooplankton community of Lake Keowee was represented primarily by microcrustaceans (copepods and cladocerans) and rotifers. The 47 genera collected (Table 6-10) included 85 identified species (10 copepods, 22 cladocerans, and 53 rotifers). Although littoral taxa were occasionally noted, the common species or taxa were characteristically limnetic types. All limnetic taxa found in the 1974 collections were also noted in the 1975 and 1976 collections. Additions to the species list in 1975 and 1976 were probably due to improved identification techniques and increased sampling frequency.

Numerically Dominant Taxa

Although the relative composition of zooplankton varied seasonally (Figure 6-13), copepods comprised yearly averages (all locations and months) of 41% (1974), 36% (1975), and 42% (1976) of the total zooplankton. Immature naupliar and copepodid forms were the primary copepod representatives throughout the three year period, constituting an average 90% of the copepod population. Abundant adults were *Diaptomus mississippiensis* and *Tropocyclops prasinus*. Together these two adults constituted an average 8% of the total copepod population and 80% of the adult copepod population.

Cladocerans were the least abundant group of zooplankton in Lake Keowee (Figure 6-13). They comprised yearly averages of 14%, 19%, and 16% of the zooplankton for 1974, 1975, and 1976, respectively. Prevalent species, *Bosmina coregoni*, *Diaphanosoma leuchtenbergianum*, and *Holopedium gibberum*, composed approximately 90% of the cladoceran population over the three year period.

Rotifers comprised yearly averages of 45%, 45%, and 42% of the zooplankton for 1974, 1975, and 1976, respectively. Rotifer species exhibited marked differences in temporal and spatial distribution, making it difficult to select only a few numerically dominant taxa. Various combinations of the following taxa represented major portions of the rotifer community over the study period: *Collotheca* spp., *Conochiloides* spp., *Conochilus unicornis*, *Gastropus stylifer*, *Keratella* spp., *Polyarthra* cf. *vulgaris*, and *Ptygura* spp.

Seasonal Analyses

The temporal distributions of major taxonomic groups and numerically dominant taxa included in each group are diagrammed in Figures 6-2 and 6-3, respectively. Densities were calculated as a grand mean of discharge area (Locations 508.0, 508.5, 504.0), intermediate area (Locations 502.0, 503.0, 505.0), and reference area (Locations 500.0, 501.0, 506.0) means. Zooplankton density in Lake Keowee varied seasonally about two orders of magnitude (4 to 100/ℓ) (Figure 6-14). It should be noted that estimated densities of zooplankton in the lake were biased towards discharge and intermediate areas since they comprised smaller surface areas of the lake (7% and 33%, respectively) than the reference areas (60%). Zooplankton standing crop in Lake Keowee was similar to standing crop in other piedmont Carolina reservoirs (King and Wetzel 1974, Weiss 1975). Copepod, cladoceran, and rotifer standing crops were usually greater from spring to early fall (thermally stratified periods) than during late fall and winter (thermally destratified period) for each year.

Variation in the seasonal abundance of zooplankton from year to year is not uncommon and often reflects natural changes in the ecosystem (natural temperature fluctuations, predation). The magnitude of total zooplankton, copepod and rotifer density peaks decreased in 1976 from those of 1974 and 1975. This decrease was not attributed to ONS operation.

Friedman Test results indicated significant year to year variation in total zooplankton standing crop in Lake Keowee for both stratified and destratified periods (Table 6-11). Total zooplankton standing crop (period average) in the lake was lower for the 1976 stratified period (41/ℓ than the 1974 and 1975 stratified periods (47/ℓ and 54/ℓ, respectively). Zooplankton standing crop in the lake was lower for 1975-76 destratified and 1976 destratified thermal periods (15/ℓ and 16/ℓ, respectively) than for the 1974-75 destratified thermal period (21/ℓ). Year to year variation in zooplankton standing crop (period average) was not attributed to ONS operation.

Considerable seasonal variation in the taxonomic composition of the zooplankton was noted (Figure 6-13). Copepods, cladocerans and rotifers constituted 16 to 69%, 2 to 40%, and 18 to 73% of the zooplankton, respectively, over the three year study period. Copepods were generally numerically dominant the first half of each year and the rotifers were numerically dominant the latter half. No major alterations in taxonomic composition were noted from 1974 to 1976 (lake average).

Copepod density was greatest in September 1974 (58/ℓ), June 1975 (50/ℓ) and May 1976 (32/ℓ) (Figure 6-41). Nauplii were the primary contributors to copepod standing crop throughout the year period (Figure 6-15). Diaptomus mississippiensis exhibited density maxima in May 1974 and 1975 (2/ℓ and 3/ℓ, respectively) and April 1976 (5/ℓ). Tropocyclops prasinus densities exceeded 1/ℓ only in May and June 1975 (3/ℓ and 4/ℓ, respectively).

Cladoceran standing crop was relatively low (1 to 23/ℓ) throughout the three year study (Figure 6-14). Total cladoceran densities were highest in September 1974 (8/ℓ), June 1975 (23/ℓ) and March 1976 (13/ℓ). Bosmina coregoni was the primary contributor to cladoceran standing crop throughout the study (Figure 6-15). Other species which occasionally were major components of the cladoceran community included Diaphanosoma leuchtenbergianum (May 1974, 3/ℓ; May 1976, 4/ℓ) and Holopedium gibberum (May 1974, 6/ℓ).

Rotifers exhibited marked seasonal fluctuations (Figure 6-14). In 1974, density peaks occurred in July, September, and October (29/ℓ, 32/ℓ, and 25/ℓ, respectively). Likewise, density was highest from summer to early fall for 1975, with densities ranging from 23/ℓ to 35/ℓ from June to September. Similar peaks were noted in 1976 with summer densities of 29/ℓ, 30/ℓ, and 17/ℓ in June, July and September, respectively. Rotifer temporal distribution patterns reflected the various seasonal patterns of several rotifer taxa (Figure 6-15).

Spatial Analyses

The relative composition of zooplankton (by major taxonomic group) from 10 m to surface at locations within and outside the ONS heated effluent is indicated in Figures 6-16 through 6-20. The seasonal taxonomic composition of zooplankton was relatively similar among representative reference (Locations 500.0, 506.0), intermediate (Locations 502.0, 505.0) and discharge (Location 508.5) areas.

Significant differences in zooplankton standing crop (10 m to surface) among locations were noted for the 1974-75 thermally destratified period (Table 6-11). Total zooplankton, copepod and rotifer densities were lower in the discharge area (Locations 508.0, 508.5, 504.0) than in the reference areas (Locations 500.0, 501.0, 506.0) (Figures 6-21, 6-22 and 6-24, respectively). Densities of the taxonomic groups at Locations 502.0, 503.0 and 505.0 were intermediate between discharge and reference area densities. Cladoceran densities were higher at reference Locations (500.0 and 501.0) than all other locations (Figure 6-23). No significant differences in zooplankton standing crop were noted for the 1974 thermally stratified period (Table 6-11).

Zooplankton standing crops were significantly different among locations for stratified 1975, destratified 1975-76, stratified 1976, and destratified 1976 thermal periods. Data from each period revealed total zooplankton, copepod and rotifer densities were substantially lower in the discharge area than in reference areas (Figures 6-21, 6-22 and 6-23, respectively). Standing crop gradually increased with increased distance from the discharge. Greater densities were noted at lesser distances from the ONS discharge in the Little River arm and connecting canal (Locations 502.0, 503.0) than in the Keowee River arm (Locations 508.5, 505.0).

The densities of most prevalent copepod and rotifer taxa were lower in the discharge area than in reference areas during the 1975 stratified, 1975-76 destratified, 1976 stratified and 1976 destratified thermal periods (Figures 6-25 through 6-28). The cladocerans, Bosmina coregoni and Holopedium gibberum (Figure 6-26), exhibited similar standing crops among locations during 1975 and 1976. The rotifer, Kellicottia bostoniensis (Figure 6-27), exhibited an increase in density in the discharge area during 1975 but not during 1976.

Total zooplankton, copepod, cladoceran and rotifer densities were greater lakeside of the skimmer wall (Location 502.0) than in the intake canal (Location 509.5) for stratified and destratified thermal periods of 1974 through 1976 (Figure 6-29). Total zooplankton densities in the intake canal were 18 to 45% and 48 to 69% of the densities lakeside of the skimmer wall for stratified and destratified periods, respectively.

Bottom to surface and 10 m to surface standing crop comparisons at Location 502.0 (Figure 6-16) indicated zooplankton were generally more abundant in the upper strata from spring to early fall (thermally stratified period). A June 10 and 11, 1975 diel study conducted at Location 502.0 indicated the numerically dominant copepods (Figure 6-30 and 6-31), cladocerans (Figure 6-32) and rotifers (Figure 6-33) were concentrated between the surface and 14 m with comparatively low numbers occurring below 14 m. Kellicottia bostoniensis was, however, consistently present in large numbers at bottom depths (18 to 22 m) at Location 502.0, which made this species susceptible to ONS entrainment. As stated earlier, K. bostoniensis densities were higher in the discharge area than in the reference area during the stratified period of 1975 (Figure 6-26).

From late fall to early spring (thermally destratified period) each year, bottom-to-surface and 10 m-to-surface tows revealed similar zooplankton densities, which indicated zooplankton were dispersed deeper in the water column (Figure 6-16). Apparently, even during destratified periods, large numbers of zooplankton were distributed above 20 m (depth of skimmer wall opening at full pond) and, therefore, did not pass under the skimmer wall (Figure 6-29). Factors such as phototaxis and food were probably responsible for this vertical distribution pattern. Zooplankton vertical distribution patterns were very similar to those of the phytoplankton (Chapter 5), a major food source for most of the prevalent zooplankton taxa of Lake Keowee.

Zooplankton standing crop in the discharge cove (Location 508.0) was very similar to standing crop in the intake canal (Location 509.5) throughout the three year study (Figure 6-29) which indicated densities in the discharge area were strongly influenced by densities in the intake canal.

ONS Operational Effects

The operation of Oconee Nuclear Station had one detectible effect on the receiving water zooplankton populations of Lake Keowee. The effect was an apparent decrease in zooplankton standing crop in the discharge (Locations 508.0, 508.5, 504.0) and intermediate (Locations 502.0, 503.0, 505.0) areas during the destratified periods of 1974, 1975 and 1976 and the stratified periods of 1975 and 1976. Densities were 65 to 71% lower in the discharge area and 29 to 58% lower in the intermediate area than densities in the reference area (Locations 500.0, 501.0, 506.0). Discharge and intermediate areas represented approximately 7% and 33%, respectively, of the total surface area of the reservoir.

Differences in zooplankton density among locations for stratified and destratified periods of 1974 through 1976, reflected ONS operating levels (expressed as CCW flow rates) and effects of the ONS skimmer wall. As previously stated, zooplankton at Location 502.0 were concentrated well above the skimmer wall opening (20 to 27 m) for most months of 1974, 1975 and 1976. Therefore, the skimmer wall was a barrier to large numbers of upper strata zooplankton. Thus, intake water, low in zooplankton density, was passed through the CCW System and discharged into the receiving waters, substantially diluting zooplankton density in the discharge area. Similar results were found in a study on the effects of Marshall Steam Station (which also has a skimmer wall) on the zooplankton populations of Lake Norman, North Carolina (Menhinick and Jensen 1974). Dilution diminished with increased distance from the discharge structure which resulted in a gradual increase in zooplankton standing crop in the intermediate area. As stated earlier, zooplankton standing crop increases were noted shorter distances from the discharge structure in the Little River arm and connecting canal (Locations 502.0, 503.0) than in the Keowee River arm (Locations 508.5, 505.0) during stratified and destratified periods of 1975 and 1976. This resulted because the majority of the ONS thermal plume was confined to the Keowee River arm of the reservoir (Chapter 2).

Although exclusion of zooplankton by the skimmer wall occurred during the stratified period of 1974 as it did with destratified 1974-75, stratified 1975, destratified 1975-76, stratified 1976 and destratified 1976 thermal periods, densities were not significantly different among locations for the 1974 stratified thermal period. For that period, the average monthly CCW flow rate (3750 m^3/min), lowest for the three year study, was not sufficient to appreciably dilute zooplankton standing crop in the discharge and intermediate areas of the lake. Average monthly CCW flows were considerably higher for all the other thermal periods (5304 to 6977 m^3/min), which resulted in substantial dilution of zooplankton standing crop in the discharge and intermediate areas. Spatial trends (location to location) were similar for 1975 and 1976 as were CCW flow rates.

Due to rapid mixing of the heated effluent in the discharge cove, the water temperature in the discharge cove rarely exceeded thermal tolerance levels (30 C) described in the literature (Bunting 1974, Goss and Bunting 1976) for most zooplankton. Maximum discharge cove temperatures (recorded at Location 508.0) occurred in September 1974, 1975, and 1976 (25.8, 31.0, and 29.6 C, respectively). Water temperatures in reference areas were similar or slightly less (1 to 2 C) than discharge cove temperatures during summer and early fall months when maximum discharge temperatures occurred (Chapter 2). Discharge temperatures recorded over the three year period were not responsible for the lower standing crop in discharge area compared to reference areas. Minimum dissolved oxygen concentrations recorded in the discharge cove during September 1974 and 1975, and August 1976 (3.4, 3.8, and 4.3 mg/l, respectively, Table 3-5) were not sufficiently low to be lethal to the zooplankton (Bogatova 1973, Kring and O'Brien 1976, Mangum and Winkle 1973, Sprague 1962).

Previous ONS operating data and future scheduled fuel loadings indicate that 1973 data should represent the most impact ONS operations are likely to have on Lake Keowee. All three units were operational during most of the summer and fall of 1975 yielding an annual gross thermal capacity factor of 69%. In the future only two units will be operational during the summer and fall when maximum plant effects occur.

The U. S. Fish and Wildlife Service Southeast Reservoir Investigations (SERI) were engaged in a zooplankton monitoring program from 1973 through 1976 to measure the impact of ONS on the distribution and abundance of zooplankton in Lake Keowee. SERI has compiled these data in a special report for Duke Power Company (Addendum A-6).

It is important to note that SERI used a larger mesh net than Duke Power Company in the collection of zooplankton samples. The 157 μm mesh netting used by SERI permitted only the collection of cladocerans and adult copepods, allowing the smaller sized rotifers and immature copepod forms to pass through the netting. Duke Power Company collections with 76 μm mesh netting permitted the collection of rotifers and immature copepods in addition to cladocerans and adult copepods. Duke Power Company data for the taxonomic composition, abundance, and temporal-spatial distribution of the cladocerans and adult copepods were in general agreement with SERI data.

The Oconee Nuclear Station FES (USAEC, 1972) predicted that zooplankton standing crops would be reduced in the discharge area during late summer (September, August) when zooplankton thermal tolerance levels were approached or exceeded. However, the reductions that have been documented in this report were attributed to dilution and not thermal stress.

SUMMARY AND CONCLUSIONS

1. The Lake Keowee zooplankton community was numerically dominated by rotifers and immature forms of cyclopoid and calanoid copepods (nauplii and copepodids). Cladocerans were the least abundant major taxonomic category of zooplankton.

2. Variations in the seasonal distribution and estimated lake abundance of zooplankton from year to year were not attributed to the operation of Oconee Nuclear Station. Furthermore, ONS operations did not alter the composition of zooplankton from year to year.

3. Zooplankton immotility (mortality) was closely associated with ambient (intake) temperature. As ambient temperature increased, the percentage of immotile and damaged zooplankton in the intake also increased.

4. The ΔT and final exposure temperature had little or no relationship to immotility. The maximum temperatures to which the zooplankton were exposed during passage through the condenser cooling water system were generally below thermal tolerance levels found in other studies.

5. Although a seasonal trend of percent immotility and percent damage was noted, there were no statistically significant differences among months or between thermal periods.

6. An average 2% of the total Crustacea entrained were immotile as a result of passage through the CCW System.

7. The ONS skimmer wall, with a 20 to 27 m depth opening, was a barrier to the larger populations of zooplankton in the upper strata lakeside of the skimmer wall. This resulted in lower zooplankton densities in the intake canal than densities lakeside of the skimmer wall. Intake water, low in zooplankton density, was passed through the ONS cooling system and discharged into the receiving waters, appreciably diluting the zooplankton community in the discharge and intermediate areas of the reservoir when condenser cooling water flow rates were sufficiently high.

8. A 65 to 71% and 29 to 58% reduction in zooplankton standing crop was noted in the discharge and intermediate areas of the reservoir, respectively. The discharge and intermediate areas comprised 7% and 33%, respectively, of the total lake surface area. These reductions for the 1974-75, 1975-76 and 1976 destratified periods and 1975 and 1976 stratified periods were related to the ONS average monthly CCW flow rates. The average monthly CCW flow rate for the 1974 stratified period was too low to appreciably dilute discharge and intermediate area standing crops.

9. SERI data suggested that bottom water withdrawal by ONS resulted in minimal entrainment of zooplankton during about 10 months of each year. This resulted in a dilution effect, creating an area of low zooplankton standing crop covering about 15% of the reservoir surface area. These findings were similar to those by Duke Power Company, although Duke Power Company data indicated that a larger surface area of the reservoir was diluted.

10. Maximum temperature and minimum dissolved oxygen concentrations recorded in the discharge cove were not lethal to most zooplankton of Lake Keowee and were not responsible for the comparatively low standing crops observed in the discharge and intermediate areas.

RECOMMENDATIONS

ENTRAINMENT

It is apparent from the data that entrainment effects of ONS on the zooplankton of Lake Keowee are small if not negligible. The presence of the skimmer wall and the moderate ΔT's and discharge temperatures recorded were three factors that helped keep entrainment effects minimal. Since such low mortalities resulted from zooplankton entrainment through the condenser system, it is unlikely that any detectable effect on the zooplankton community would ever result.

Because of the results of this study, we recommend that all requirements for zooplankton entrainment studies (Specification 1.5) be deleted from the ONS Technical Specifications.

RECEIVING WATER

The operational effects of ONS on the receiving water zooplankton population of Lake Keowee have been documented and shown to have stabilized. Lower densities in the discharge and intermediate areas were related to dilution and not thermal stress.

Based on conclusions drawn from this study, it is recommended that all requirements for the plankton receiving water study (Specification 1.3.4) be deleted from the ONS Technical Specifications.

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Table 6-1

Summary of Entrainment Studies on Zooplankton from various freshwater ecosystems.

Zooplankton Category	Location	Major Conclusions	Maximum Discharge Temperature (C)	ΔT (C°)	Author
Microcrustacea	Lake Norman N.C.	Greatest immotility (mortality) was found at the lowest ambient temperature (8 C). Maximum discharge temperature was below the maximum thermal tolerance for the majority of the zooplankton	33	11 - 20	Davies, et al. 1974
Microcrustacea	Lake Michigan	55% mortality attributed to thermal and mechanical effects	$\bar{x}$ = 15.4 (n = 13)	$\bar{x}$ = 6.6	EPA, 1972
Microcrustacea	Lake Michigan	7% mortality attributed to thermal and mechanical effects	$\bar{x}$ = 9.3 (n = 4)	$\bar{x}$ = 7.4	EPA, 1972
Microcrustacea and Rotifers	Merrimack River, N.H.	The ΔT had a significant effect on the plankton suspended in it. Discharge temperatures in excess of 37.7 C caused significant changes in frequency of occurrence of various zooplankton groups	42.2	16	Normandeau, 1969
Microcrustacea	Lake Wylie, N.C.	Immotility ranged from 13.3% to 85.6% in the discharge canal. The higher immotilites were attributed to the high discharge temperatures. 5% of the immotile organisms in the discharge recovered 24 hours after entrainment	39.5	14	Industrial Biotest 1974
Microcrustacea	Lake Michigan, IL	Immotility due to thermal stress during condenser passage ranged from 0% to 5%. Mechanical abrasion was responsible for 2% to 11% of the immotility. Number of zooplankton affected by condenser passage was a linear function of size. Lethal temperatures beyond the range of tolerance were not reached.	32	5.5 - 12.5	Industrial Biotest 1974
Microcrustacea and Rotifers	Melton Hill Reservoir TN	Additon of heat to the cooling water increased the net impact 2.4% over a mechanical impact of 1.1%. No significant relationship between ΔT and percentage immobile (=immotile) for any of the taxonomic groups present.	25.8	0.0 - 10.3	Urban, et al. 1974
Microcrustacea	Lake Ontario, N.Y.	At temperatures below 35C, mortality (motility) between the intake (18.3%) and discharge (25.5%) were not significantly different. Up to 20% of the mortality could be attributed to mechanical damage. Above 35 C lethality increased rapidly to 100% at 40.5 C. Found no significant latent mortality.	40.5	7	Storr, 1974

Table 6-2

Summary of Oconee Nuclear Station Zooplankton Entrainment Sampling Program

	Intake	Pre-cond	Post-cond	Discharge
19 Sep 1973		X	X	
14 Nov 1973		X	X	
23 Jan 1974		X	X	
20 Mar 1974		X	X	
12 Jun 1974		X	X	
16 Jul 1974		X	X	
11 Nov 1974		X*	X*	
11 Dec 1974		X*	X*	
12 Feb 1975	X	X*	X*	X
13 Mar 1975	X	X*	X*	X
21 May 1975	X	X*	X*	X
16 Jul 1975	X	X*	X*	X
10 Sep 1975	X	X*	X*	X
12 Nov 1975	X	X*	X*	X
14 Jan 1976	X*	X*	X*	X*
17 Mar 1976	X*	X*	X*	X*
3 Apr 1976	X*	X*	X*	X*
6 Apr 1976	X*	X*	X*	X*
9 Apr 1976	X*	X*	X*	X*
14 Apr 1976	X*	X*	X*	X*
11 May 1976	X*	X*	X*	X*
8 Jul 1976	X*	X*	X*	X*
15 Sep 1976	X*	X*	X*	X*
10 Nov 1976	X*	X*	X*	X*

X indicates station was sampled on that date

* morning and afternoon replicate samples collected

Table 6-3

Spearman Rank Order Correlation for Percent Immotile Versus Selected Physical-Chemical Parameters

Site	Unit I Pre-condenser			Unit I Post-condenser			Intake			Discharge		
Taxa	Cladocera	Copepoda	Total Crustacea	Cladocera	Copepoda	Total Crustacea	Cladocera	Copepoda	Total Crustacea	Cladocera	Copepoda	Total Crustacea
Physical-Chemical Parameters												
Intake Temperature	0.391* 0.029** 31***	0.393 0.028 31	0.494 0.004 31	0.462 0.008 31	0.302 0.098 31	0.350 0.053 31	0.593 0.009 18	0.512 0.029 18	0.494 0.037 18	0.716 <0.001 18	0.778 <0.001 18	0.804 <0.001 18
Discharge Temperature										0.423 0.079 18	0.578 0.011 18	0.546 0.018 18
Pre-condenser Temperature	0.380 0.034 31	0.431 0.015 31	0.520 0.002 31	0.404 0.024 31	0.296 0.105 31	0.325 0.073 31				0.664 0.018 12	0.792 0.002 12	0.791 0.002 12
Post-condenser Temperature				0.508 0.003 31	0.347 0.055 31	0.388 0.030 31				0.299 0.343 12	0.703 0.010 12	0.670 0.017 12
Unit I Condenser Δ T				0.484 0.005 31	0.135 0.465 31	0.227 0.217 31						
Intake-Discharge Δ T										-0.344 0.161 18	-0.137 0.586 18	-0.228 0.360 18
Unit I Flow (m^3/ sec.)	0.234 0.203 31	0.356 0.048 31	0.358 0.047 31	0.388 0.030 31	0.239 0.194 31	0.276 0.132 31						
ONS Flow (m^3/ sec.)										0.283 0.254 18	0.170 0.497 18	0.191 0.445 18
Intake Dissolved Oxygen	-0.396 0.027 31	-0.355 0.049 31	-0.464 0.008 31	-0.497 .004 31	-0.415 0.020 31	-0.465 0.008 31	-0.460 0.054 18	-0.413 0.088 18	-0.360 0.141 18	-0.744 <0.001 18	-0.559 0.015 18	-0.633 0.004 18
Location 502.0 Thermal Gradient	0.254 .167 31	0.100 0.591 31	0.202 0.274 31	0.402 0.024 31	0.166 0.371 31	0.242 0.189 31	0.086 0.732 18	0.159 0.528 18	0.126 0.617 18	0.433 0.072 18	0.352 0.151 16	0.382 0.117 18

* Spearman correlation coefficient
** Probability of greater /R/ by chance under H_o:ρ=0
*** Number of observations

Table 6-4

Spearman Rank Order Correlation for Corrected Percent Immotile Versus Selected Physical-Chemical Parameters

Site	Unit I Pre-cond. - Post cont.			Intake - Discharge		
Taxa	Cladocera	Copepoda	Total Crustacea	Cladocera	Copepoda	Total Crustacea
Physical-Chemical Parameters						
Intake Temperature	0.126* 0.501** 31***	0.047 0.803 31	-0.641 0.732 31	0.078 0.759 18	0.655 0.003 18	0.506 0.032 18
Discharge Temperature				-0.076 0.756 18	0.745 <0.001 18	0.486 0.041 18
Pre-condenser Temperature	0.034 0.854 31	0.002 0.993 31	-0.095 0.612 31	-0.088 0.785 12	0.538 0.071 12	0.278 0.381 12
Post-condenser Temperature	0.238 0.197 31	0.126 0.497 31	0.081 0.665 31	-0.427 0.166 12	0.618 0.321 12	0.109 0.734 12
Unit I Condenser ΔT	0.373 0.039 31	0.177 0.341 31	0.219 0.237 31			
Intake-Discharge ΔT				-0.101 0.689 18	0.225 0.369 18	0.095 0.708 18
Unit I Flow (m^3/sec.)	0.154 0.407 31	0.041 0.826 31	-0.073 0.696 31			
ONS Flow (m^3/sec.)				-0.178 0.479 18	0.366 0.135 18	0.154 0.543 18
Intake Dissolved Oxygen	-0.148 0.428 31	-0.198 0.286 31	0.004 0.984 31	-0.248 0.322 18	-0.489 0.040 18	-0.525 0.025 18
Location 502.0 Thermal Gradient	0.161 0.386 31	0.167 0.370 31	0.031 0.870 31	0.461 0.054 18	0.415 0.087 18	0.514 0.029 18

* Spearman correlation coefficient

** Probability of greater /R/ by chance under $H_0:\rho=0$

*** Number of observations

Table 6-5

Spearman Rank Order Correlation for Percent Damage Versus Selected Physical-Chemical Parameters

Site	Unit I Pre-condenser			Unit I Post-condenser			Intake			Discharge		
Taxa	Cladocera	Copepoda	Total Crustacea	Cladocera	Copepoda	Total Crustacea	Cladocera	Copepoda	Total Crustacea	Cladocera	Copepoda	Total Crustacea
Physical-Chemical Parameters												
Intake Temperature	0.572 0.011 19	0.512 0.025 19	0.606 0.006 19	0.560 0.013 19	0.560 0.013 19	0.645 0.003 19	0.114 0.673 16	0.356 0.175 16	0.485 0.056 16	0.562 0.023 16	0.575 0.198 16	0.602 0.014 16
Discharge Temperature										0.515 0.041 16	0.754 <0.001 16	0.639 0.008 16
Pre-condenser Temperature	0.565 0.012 19	0.521 0.022 19	0.609 0.006 19	0.537 0.018 19	0.555 0.014 19	0.635 0.004 19				0.640 0.025 12	0.404 0.193 12	0.610 0.035 12
Post-condenser Temperature				0.571 0.011 19	0.530 0.020 19	0.621 0.005 19				0.679 0.015 12	0.509 0.091 12	0.690 0.013 12
Unit I Condenser Δ T				0.399 0.090 19	0.051 0.835 19	0.236 0.331 19						
Intake-Discharge Δ T										-0.029 0.915 16	0.277 0.300 16	0.064 0.813 16
Unit I Flow (m^3/sec.)	0.633 0.004 19	0.549 0.015 19	0.596 0.007 19	0.677 0.001 19	0.608 0.006 19	0.693 0.001 19						
ONS Flow (m^3/sec.)										0.167 0.537 16	0.421 0.104 16	0.332 0.209 16
Intake Dissolved Oxygen	-0.695 <0.001 19	-0.387 0.102 19	-0.637 0.003 19	-0.765 <0.001 19	-0.580 0.009 19	-0.787 <0.001 19	-0.133 0.624 16	-0.363 0.167 16	-0.513 0.042 16	-0.650 0.006 16	-0.386 0.140 16	-0.610 0.012 16
Location 502.0 Thermal Gradient	0.706 <0.001 19	0.108 0.660 19	0.540 0.017 19	0.782 <0.001 19	0.382 0.107 19	0.663 0.002 19	0.502 0.047 16	0.322 0.223 16	0.516 0.041 16	0.705 0.002 16	0.369 0.160 16	0.614 0.012 16

* Spearman correlation coefficient
** Probability of greater /R/ by chance under $H_o:\rho=0$
*** Number of observations

Table 6-6

Percent immotile at the intake and discharge based on the total number of organisms observed over the study period.

Site	Intake		Discharge	
Taxa	Number Observed	Percent Immotile	Number Observed	Percent Immotile
Cladocera	1,343	5.1	1,329	7.1
Copepoda	3,094	16.4	3,186	18.5
Total Crustacea	4,437	13.0	4,515	15.2

Table 6-7

Summary of zooplankton sampling program indicating sampling frequency, location, and apparatus.

Collection Date	Sampling Apparatus	500.0	501.0	502.0	503.0	508.5	508.0	504.0	505.0	506.0	510.0	511.0	509.5	509.0
		SAMPLING LOCATIONS												
17 Jul 1973	1	X		X	X				X	X				
18 Sep 1973	2	X			X		X		X	X			X	
14 Nov 1973	2	X			X		X		X	X			X	
22 Jan 1974	2	X			X	X	X		X	X			X	
19 Mar 1974	2	X		X	X	X	X		X	X			X	
22 May 1974	2	X		X	X	X	X		X	X	X	X	X	
17 Jul 1974	2	X		X	X	X	X		X	X	X	X	X	
13 Aug 1974	3	X		X	X			X	X	X	X	X	X	
10 Sep 1974	3	X		X	X	X	X	X	X	X	X	X	X	
16 Oct 1974	3	X		X	X	X	X	X	X	X	X	X	X	
13 Nov 1974	3	X		X	X	X	X	X	X	X	X	X	X	
10 Dec 1974	3	X		X	X	X	X	X	X	X	X	X	X	
30 Jan 1975	3	X		X	X	X	X	X	X	X	X	X	X	
11 Feb 1975	3	X	X	X	X	X	X	X	X	X	X	X	X	X
12 Mar 1975	3	X	X	X	X	X	X	X	X	X	X	X	X	X
16 Apr 1975	3	X	X	X	X	X	X	X	X	X	X	X	X	X
20 May 1975	3	X		X	X	X	X	X	X	X	X	X	X	X
10 Jun 1975	3	X		X*	X	X	X	X	X	X	X	X	X	X
15 Jul 1975	3	X		X	X	X	X	X	X	X			X	
19 Aug 1975	3	X	X	X	X	X	X	X	X	X			X	
9 Sep 1975	3	X	X	X	X	X	X	X	X	X			X	
14 Oct 1975	3	X	X	X	X	X	X	X	X	X			X	
11 Nov 1975	3	X	X	X	X	X	X	X	X	X			X	
9 Dec 1975	3	X	X	X	X	X	X	X	X	X			X	
13 Jan 1976	3	X	X	X	X	X	X	X	X	X			X	
11 Feb 1976	3	X	X	X	X	X	X	X	X	X			X	
16 Mar 1976	3	X	X	X	X	X	X	X	X	X			X	
15 Apr 1976	3	X	X	X	X	X	X	X	X	X			X	
12 May 1976	3	X	X	X	X	X	X	X	X	X			X	
15 Jun 1976	3	X	X	X	X	X	X	X	X	X			X	
9 Jul 1976	3	X	X	X	X	X	X	X	X	X			X	
11 Aug 1976	3	X	X	X	X	X	X	X	X	X			X	
14 Sep 1976	3	X	X	X	X	X	X	X	X	X			X	
12 Oct 1976	3	X	X	X	X	X	X	X	X	X			X	
9 Nov 1976	3	X	X	X	X	X	X	X	X	X			X	
14 Dec 1976	3	X	X	X	X	X	X	X	X	X			X	

1 Portable gasoline pump equipped 2.5 cm intake hose
2 Clark-Bumpus equipped with 76μ mesh net and bucket
3 76μ mesh 0.5 m plankton net (mouth diameter) and bucket equipped with General Oceanics flowmeter

* June 10, 11 diel sampling with Schindler Plankton Trap
X Samples collected

Table 6-8

Description and classification of zooplankton sampling locations on Lake Keowee, South Carolina. January 1974 through December 1976.

Sampling Location	Description	Classification
500.0*	approximately 14 km up Little River arm from discharge structure	Reference area
501.0	approximately 10 km up Little River arm from discharge structure	
506.0*	approximately 9 km up Keowee River arm from discharge structure	
502.0*	lake-side of skimmer wall, approximately 3 km up Little River Arm from discharge structure	Intermediate area
503.0*	Keowee River-Little River connecting canal, approximately 1 km from discharge structure	
505.0*	approximately 5 km up Keowee River arm from discharge structure	
504.0 508.5*	≤1 km up Keowee River arm from discharge structure	Discharge area
508.0*	immediately facing discharge structure	ONS Discharge cove
509.5*	immediately facing intake structure	ONS Intake canal

*locations included in the statistical analyses

Table 6-9

Summary of thermal periods, months, and effects tested by the Friedman Analysis of variance. Major taxonomic groups (Copepoda, Cladocera, Rotifera, Total Zooplankton) were tested for each thermal period.

Thermal Period	Months	Effect
Stratified 1974	May, Jul 1974	1
Destratified 1974-75	Sep, Oct, Nov, Dec 1974 Jan, Feb, Mar, Apr 1975	1
Stratified 1975	May, Jun, Aug, Sep 1975	1
Destratified 1975-76	Oct, Nov, Dec 1975 Jan, Feb 1976	1
Stratified 1976	Apr, May, Jun, Jul, Aug 1976	1
Destratified 1976	Sep, Oct, Nov, Dec 1976	1
Stratified 1974-76		2,3
Destratified 1974-76		2,3

1 location over months
2 location over years
3 year over years

Table 6-10

Zooplankton Taxa of Lake Keowee
Collected through December 1976

	1974	1975	1976
Arthropoda			
Crustacea			
Copepoda			
Calanoida			
Diaptomus mississippiensis Marsh	x	x	x
Cyclopoida			
Cyclops thomasi (Forbes)	x	x	x
Eucyclops agilis (Koch)	x	x	x
Eucyclops prionophorus (Kiefer)	x	x	x
Mesocyclops edax Forbes	x	x	x
Orthocyclops modestus (Herrick)	x	x	x
Paracyclops fimbriatus (Fischer)		x	
Tropocyclops prasinus Fischer	x	x	x
Harpacticoida			
Canthocamptus cf. *assimilis* Kiefer			x
Canthocamptus cf. *sinuus* Coker			x
Cladocera			
Alona affinis (Leydig)		x	
Alona gutatta Sars	x	x	x
Alona quadrangularis (Muller)	x		
Alona setulosa (Megard)	x		
Bosmina coregoni Baird	x	x	x
Camptocercus rectirostris (Schødler)	x	x	x
Ceriodaphnia lacustris (Birge)	x	x	x
Ceriodaphnia reticulata (Jurine)	x	x	x
Chydorus piger Sars		x	
Chydorus sphaericus (Müller)	x	x	x
Daphnia ambigua Scourfield	x	x	x
Daphnia laevis Birge	x	x	x
Daphnia parvula Fordyce	x	x	x
Diaphanosoma brachyurum (Liéven)		x	
Diaphanosoma leuchtenbergianum Fischer	x	x	x
Disparalona acutirostris (Frey)		x	x
Holopedium gibberum Zaddach	x	x	x
Ilyocryptus spinifer Herrick	x	x	x
Leptodora kindtii (Focke)	x	x	x
Leydigia leydigi (Leydig)			x
Sida crystallina Müller	x	x	x
Simocephalus expinosus Birge	x	x	x
Rotifera			
Asplanchna amphora Western	x	x	
Asplanchna priodonta Ehrenberg	x	x	x
Brachionus angularis Gosse	x	x	
Brachionus patulus (Müller)	x	x	x
Chromogaster ovalis (Bergendel)		x	x
Collotheca balatonica Varga	x	x	x
Collotheca discophora (Skorikov)	x	x	x
Collotheca libera (Zachairas)	x	x	x
Collotheca mutabilis Hudson	x	x	x
Conochiloides coenobasis (Skorikov)	x	x	x
Conochiloides natans (Seligo)	x	x	x

Table 6-10

Rotifera *(continued)*	1974	1975	1976
Conochilus unicornis Rousselet	x	x	x
Dipleuchlanis spp.		x	x
Euchlanis spp.	x	x	x
Filinia spp.	x	x	
Gastropus stylifer Imhof	x	x	x
Hexarthra mira (Hudson)	x	x	x
Kellicottia bostoniensis (Rousselet)	x	x	x
Keratella americana Carlin	x	x	x
Keratella cochlearis (Gosse)	x	x	x
Keratella crassa Ahlstrom	x	x	x
Keratella earlinae Ahlstrom			x
Lecane acronycha Harring and Myers		x	x
Lecane crepida Harring and Myers			x
Lecane depressa (Bryce)		x	
Lecane flexilis (Gosse)			x
Lecane haliclysta Harring and Myers		x	x
Lecane hornemani (Ehrenberg)		x	x
Lecane leontina (Turner)		x	
Lecane luna (Müller)		x	x
Lecane mira (Murray)			x
Lecane ploenensis (Voigt)		x	x
Lecane spp.	x	x	x
Lepadella spp.	x	x	x
Macrochaetus subquadratus Perty	x	x	x
Monostyla crenata Harring			x
Monostyla lunaris (Ehrenberg)	x	x	x
Monostyla quadridentata Ehrenberg	x	x	
Monostyla stenroosi Meissener		x	x
Monostyla spp.	x	x	x
Noltholca spp.		x	x
Platyias quadricornis (Ehrenberg)	x	x	x
Ploesoma hudsoni (Imhof)	x	x	x
Ploesoma truncatum (Levander)	x	x	x
Polyarthra euryptera Wierzejski	x	x	x
Polyarthra dolichoptera (Idelson)		x	x
Polyarthra major Burckhardt	x	x	x
Polyarthra vulgaris Carlin	x	x	x
Ptygura libera Myers	x	x	x
Ptygura spp.		x	x
Synchaeta pectinata Ehrenberg	x	x	x
Trichocerca capucina Wierz	x	x	x
Trichocerca chattoni (de Beauchamp)		x	x
Trichocerca cylindrica (Imhof)	x	x	x
Trichocerca longiseta (Schrank)	x	x	x
Trichocerca multicrinis (Kellicott)		x	x
Trichocerca platessa (Meyers)			x
Trichocerca porcellus (Gosse)	x	x	x
Trichocerca pusilla (Jennings)			x
Trichocerca similis (Wierzejski)	x	x	x
Trichocerca stylata (Gosse)			x
Trichotria spp.	x	x	x
Unidentified Bdelloidea		x	x
Unidentified Rotifer	x	x	x

Table 6-11

Summary of Friedman Analysis of Variance Test results for major taxonomic categories of zooplankton during stratified and destratified periods of 1974 through 1976

Data Groups (by thermal period)	Treatment/ Block	ANOVA SS Copepoda	Cladocera	Rotifera	Total Zooplankton
Stratified 1974	1	30.0	8.0	18.0	44.0
Destratified 1974-75	1	168.3*	104.6*	46.0*	118.7*
Stratified 1975	1	101.5	84.0	100.5*	147.0*
Destratified 1975-76	1	159.5*	96.4*	143.4*	157.7*
Stratified 1976	1	179.1*	70.7	171.6*	191.6*
Destratified 1976	1	100.4*	25.1	122.5*	102.8*
Stratified 1974-76	2	91.3*	30.0	56.0	58.0
	3	2.3	3.0	3.3	7.8*
Destratified 1974-76	2	108.0*	70.7	86.0*	95.3*
	3	2.3	2.3	12.0*	7.0*

1 location/month
2 location/year
3 period/year
* Significant at $P \leq 0.05$ when compared to [# treatments X (# treatments - 1)] X Chi-Square (with # treatments - 1 DF)]/12

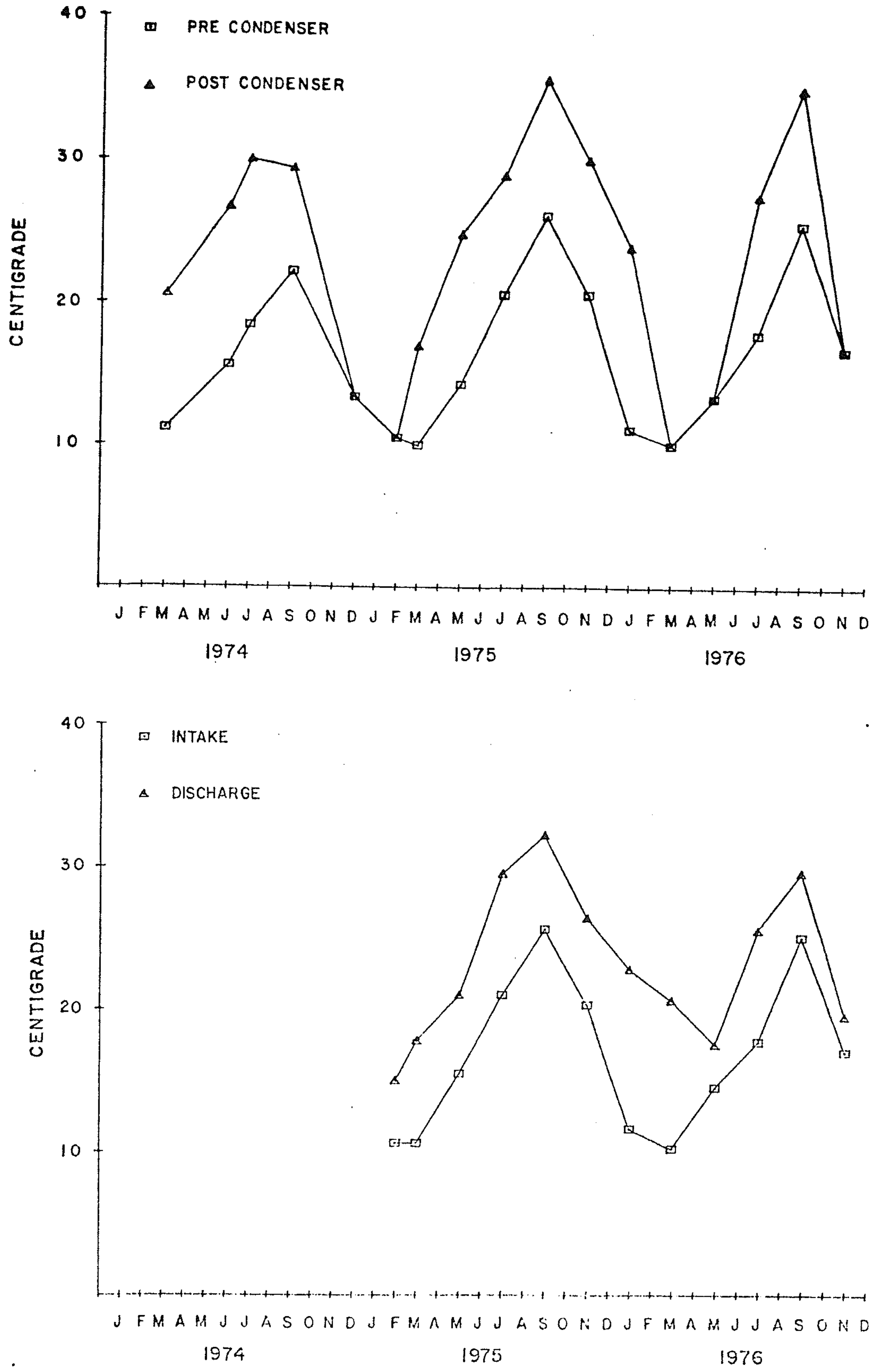


Figure 6-1. Temperatures recorded at the entrainment sample locations on the date of sampling.

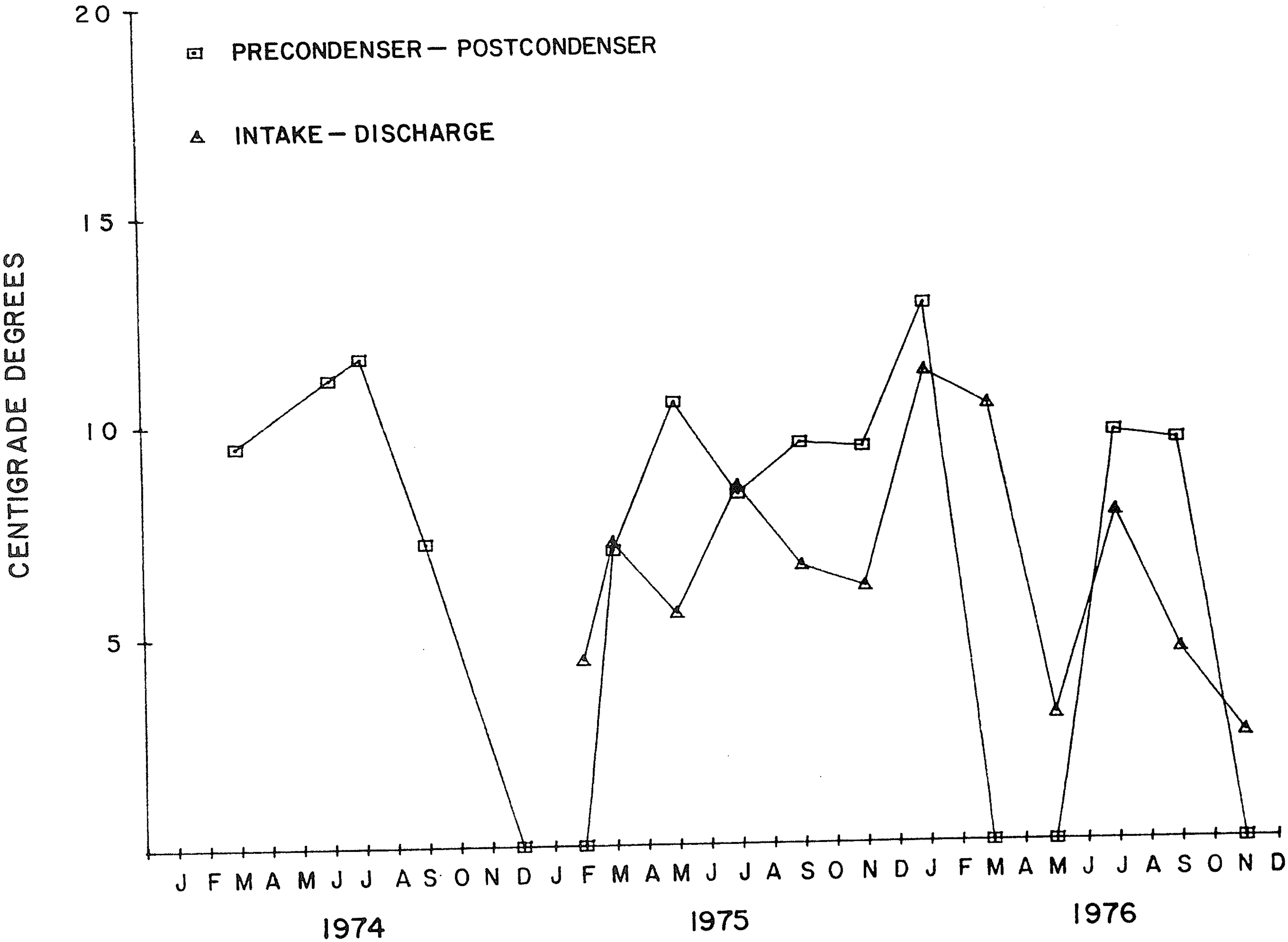


Figure 6-2. Changes in temperature between precondenser-postcondenser sample locations and between intake-discharge sample locations on the date of sampling.

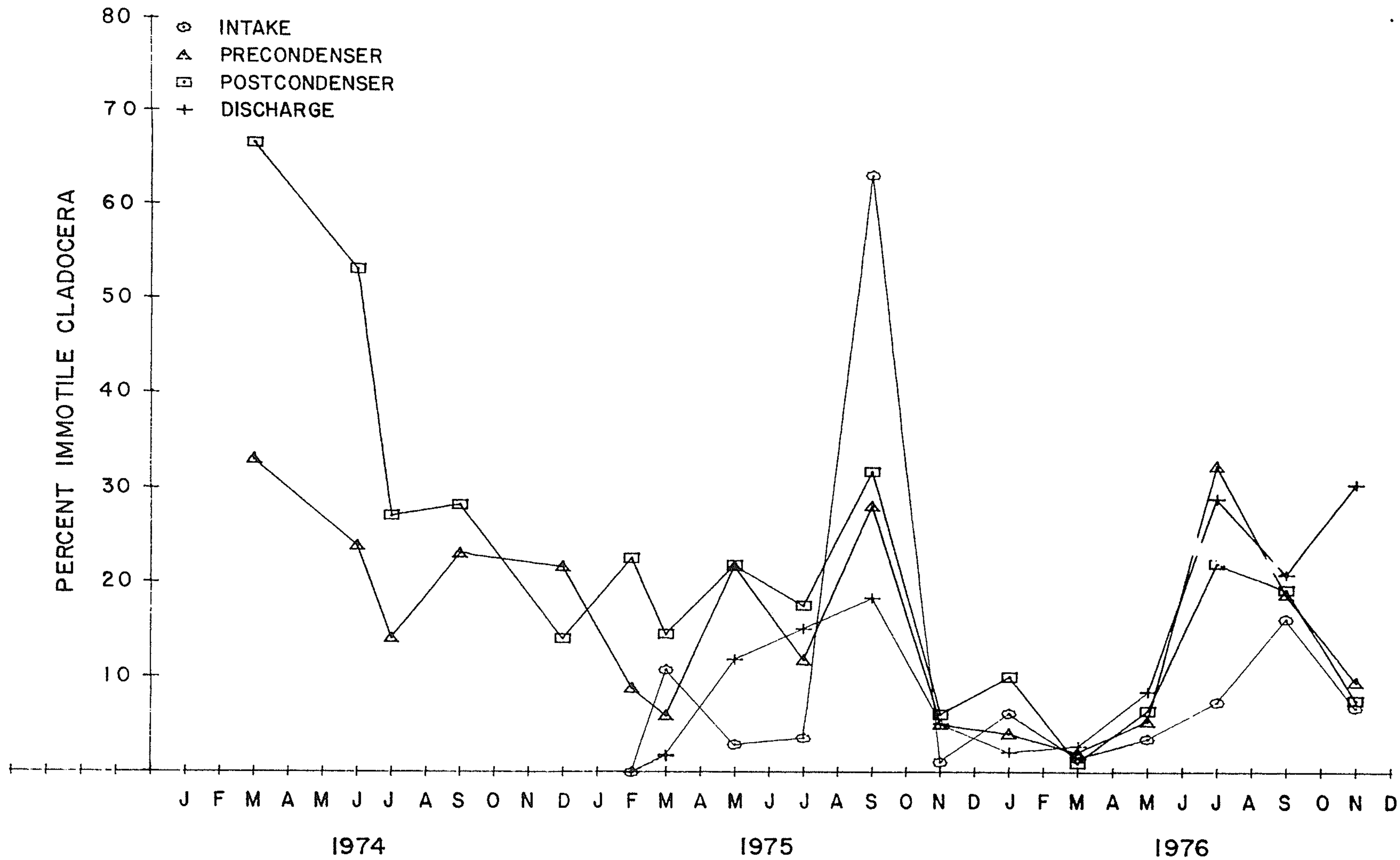


Figure 6-3. Percent immotile Cladocera at four sampling locations. Values are means of replicates.

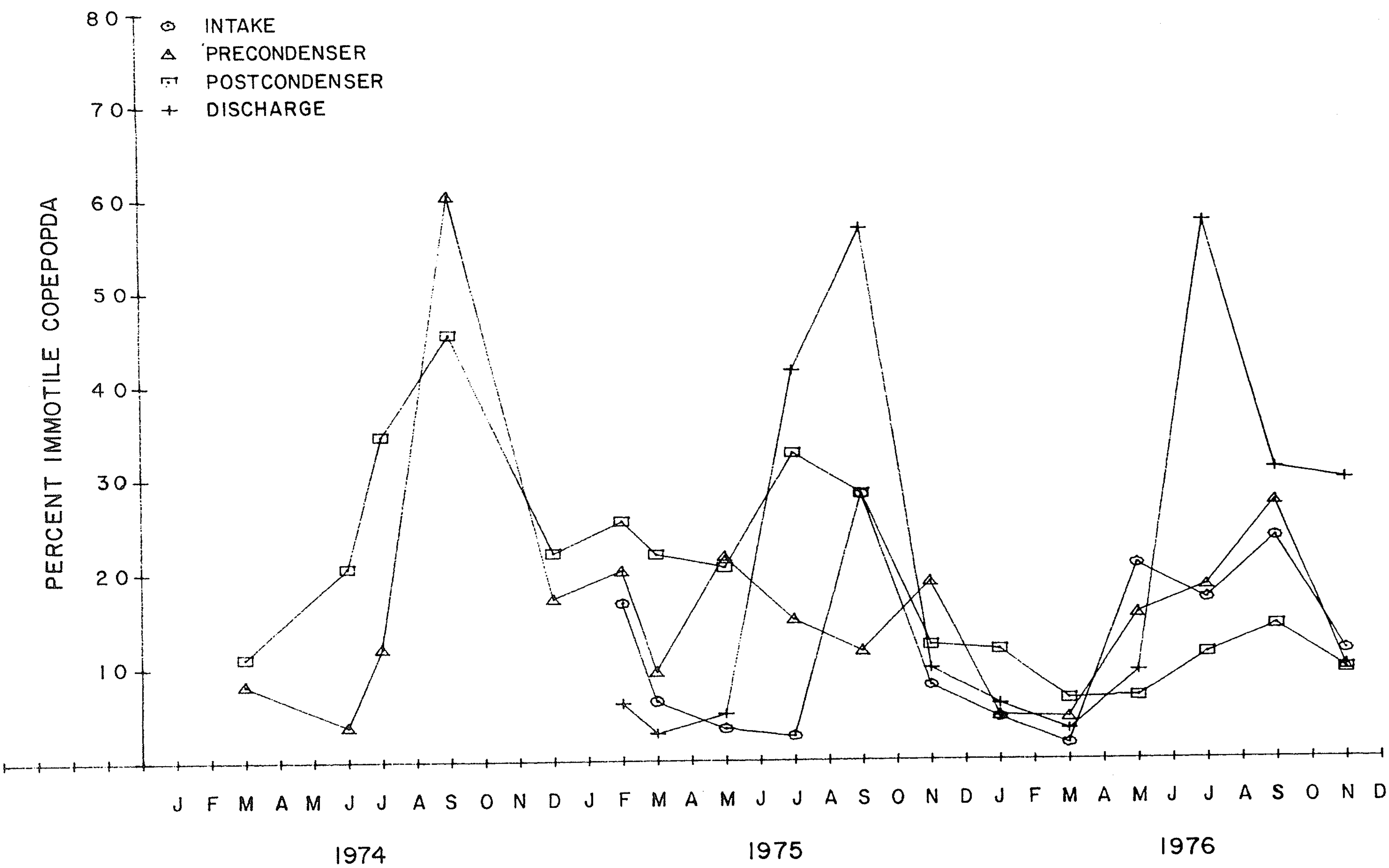


Figure 6-4. Percent immotile Copepoda at four sampling locations. Values are means of replicates.

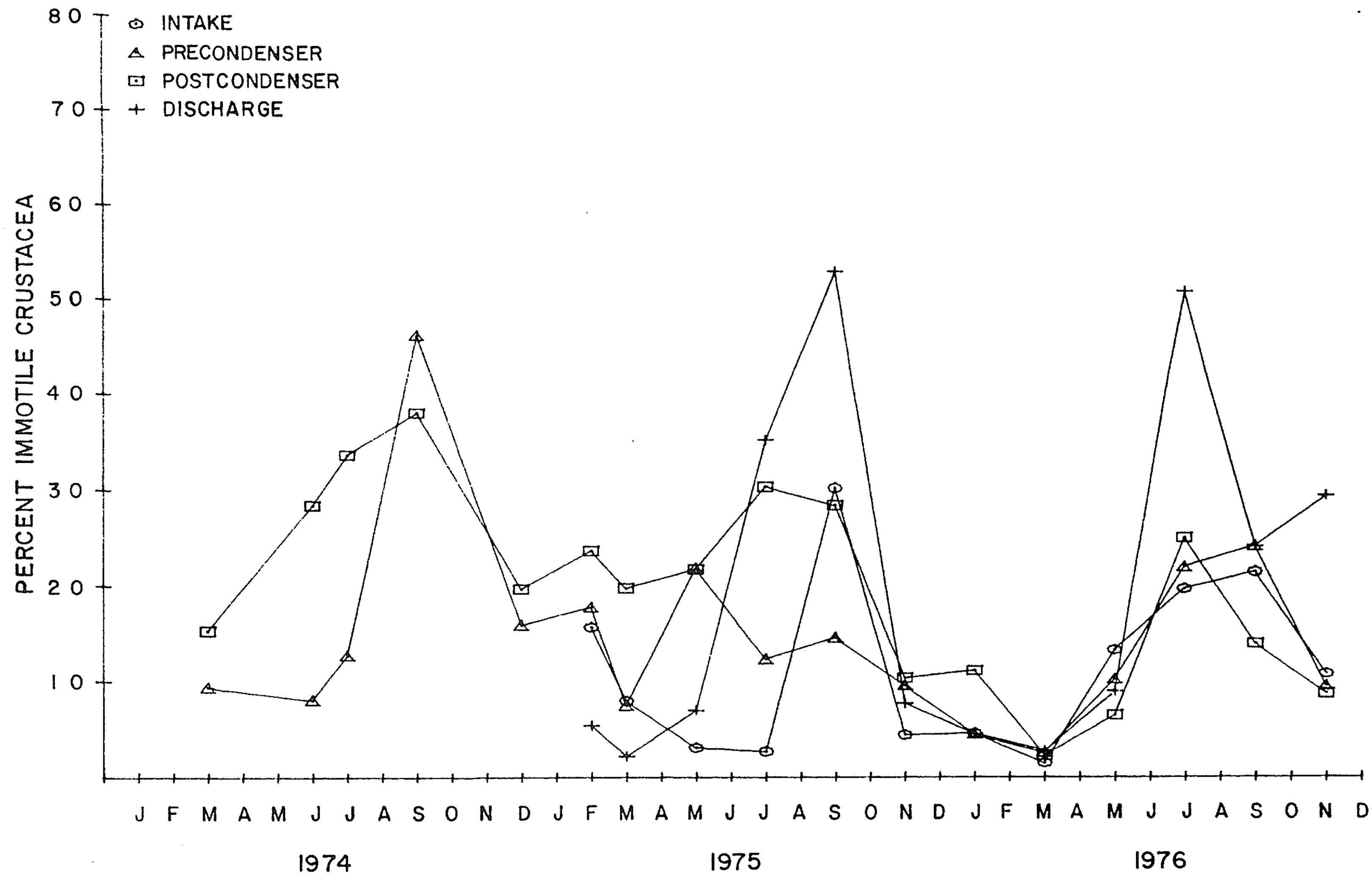


Figure 6-5. Percent immotile total Crustacea at four sampling locations. Values are means of replicates.

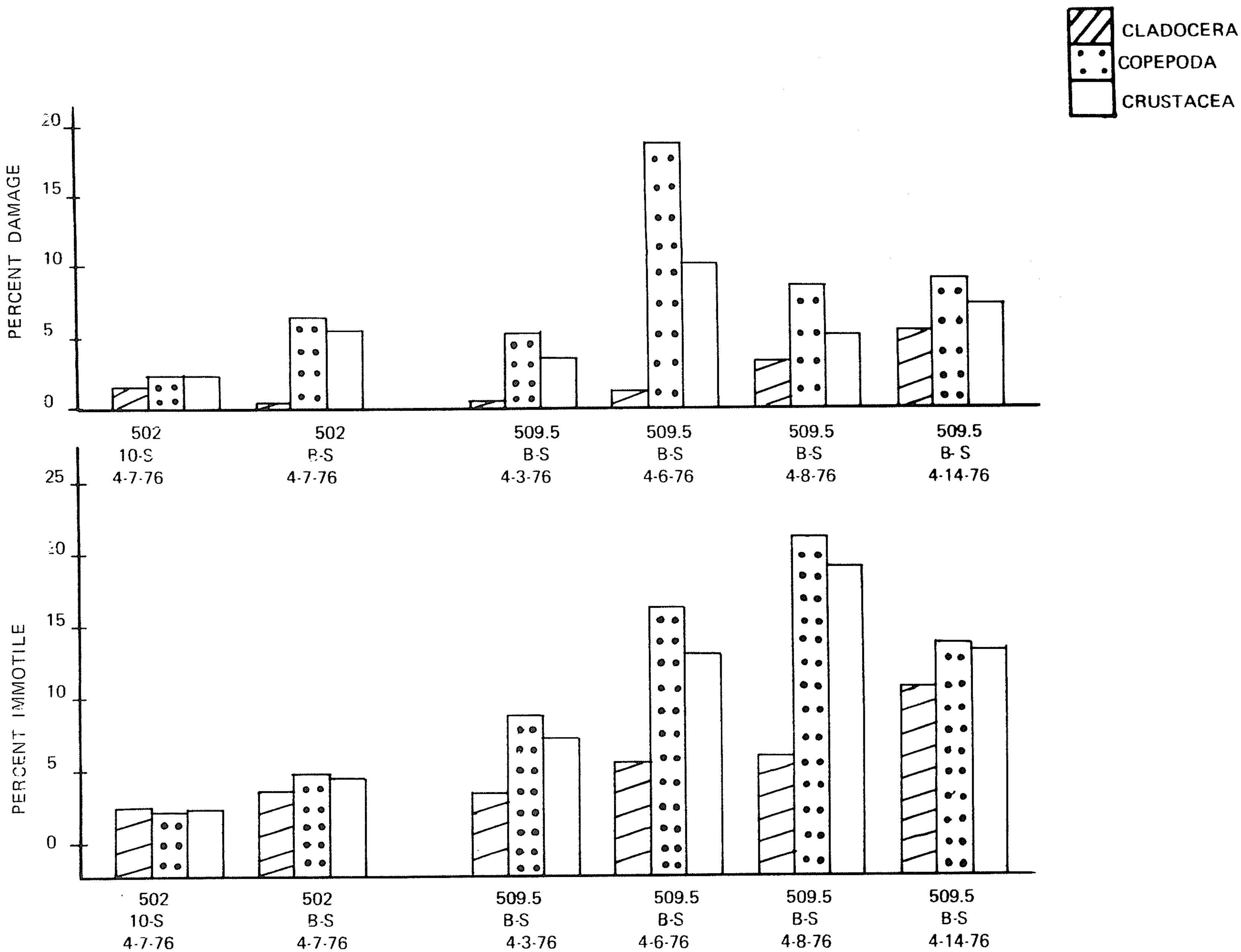


Figure 6-6. Percent Immotile and Percent Damage for Open Lake (502) and Intake (509.5).

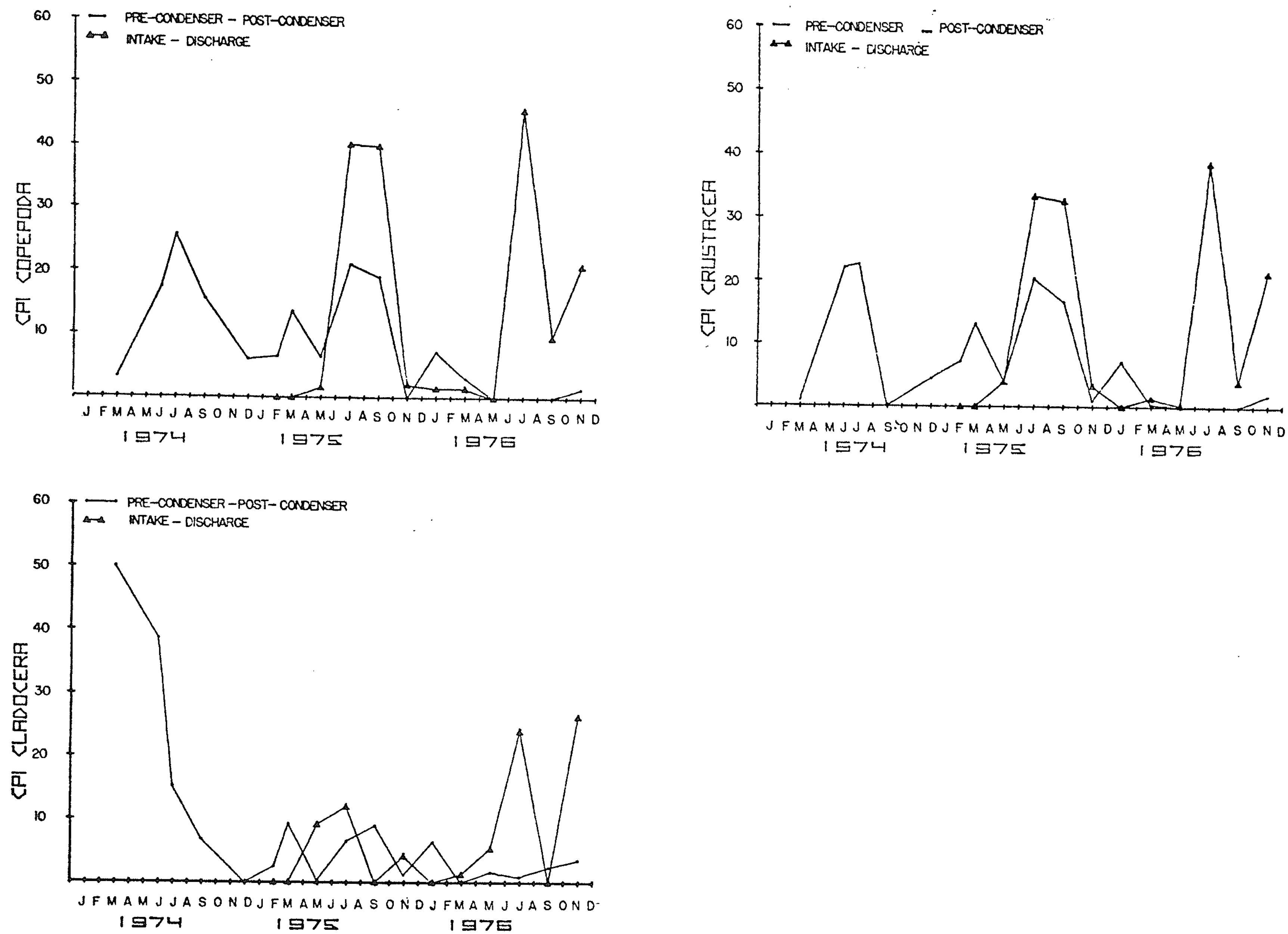


Figure 6-7. Corrected percent immotile (CPI) for the major taxonomic categories. Values are means of replicates.

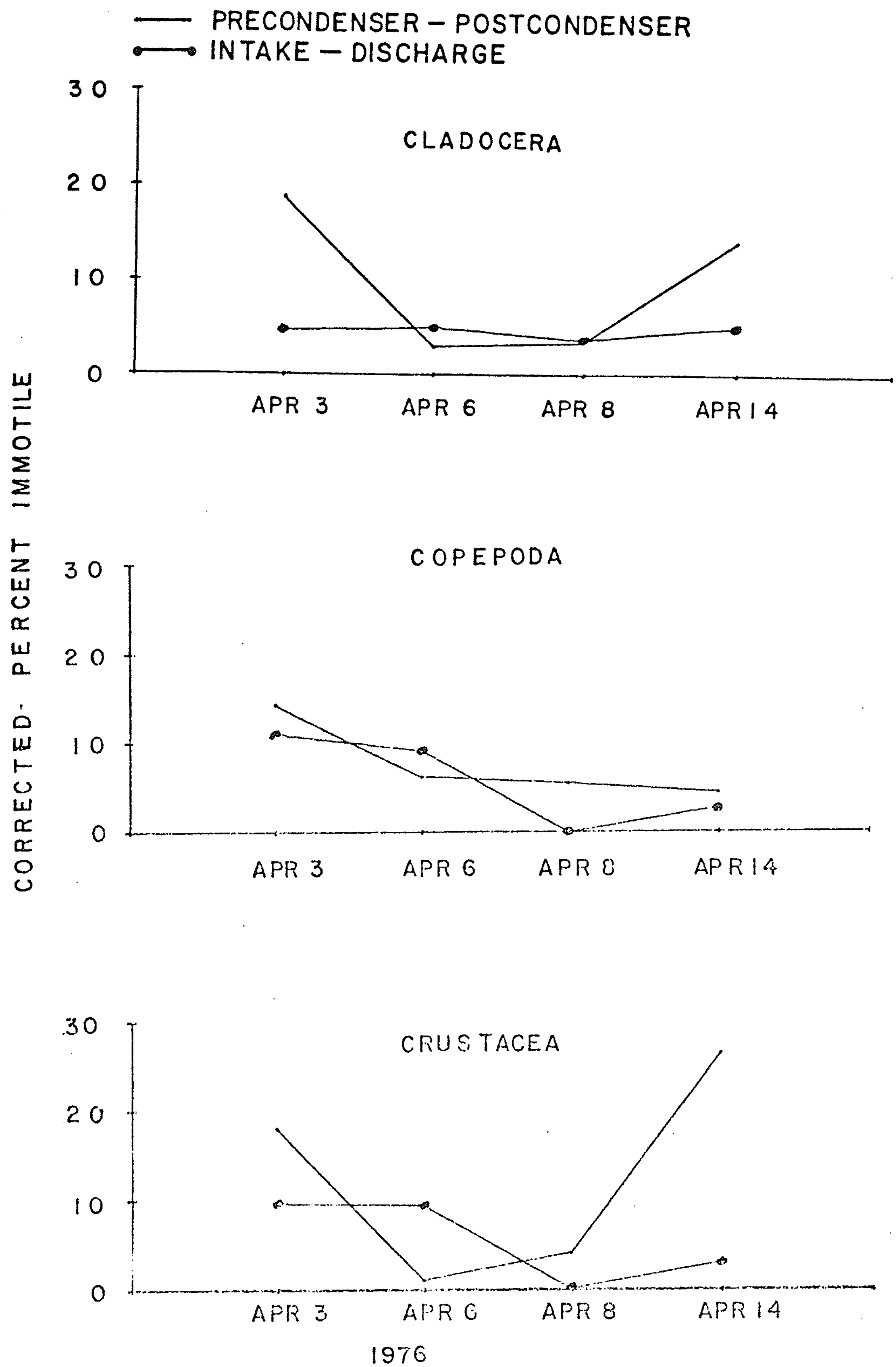


Figure 6-8. Corrected percent immotile for increasing power level study. Values are means of replicates.

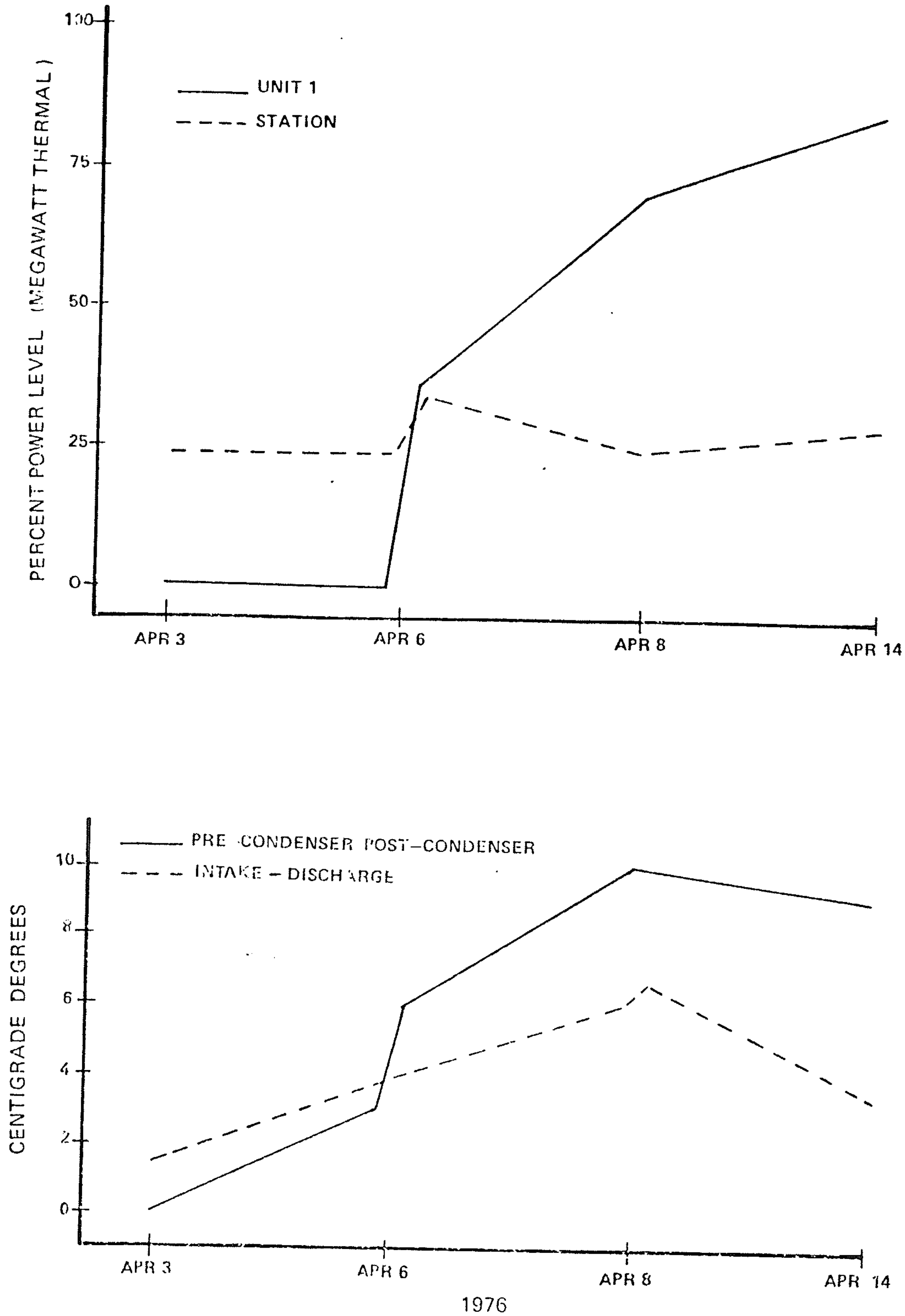


Figure 6-9. ΔT in Centigrade Degrees and Percent Power Level in Megawatts Thermal.

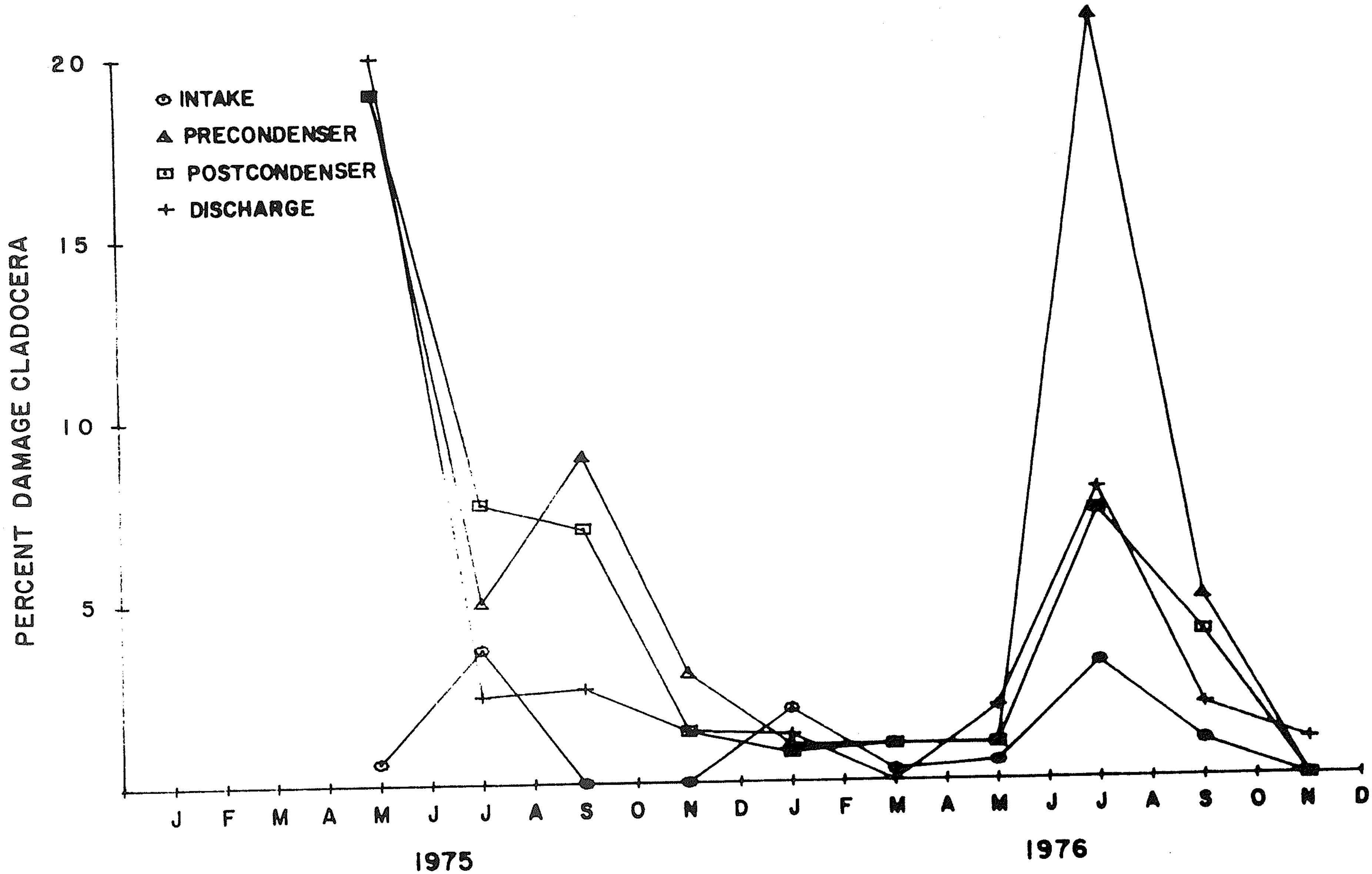


Figure 6-10. Percent damage for Cladocera at four sampling locations. Values are means of replicates.

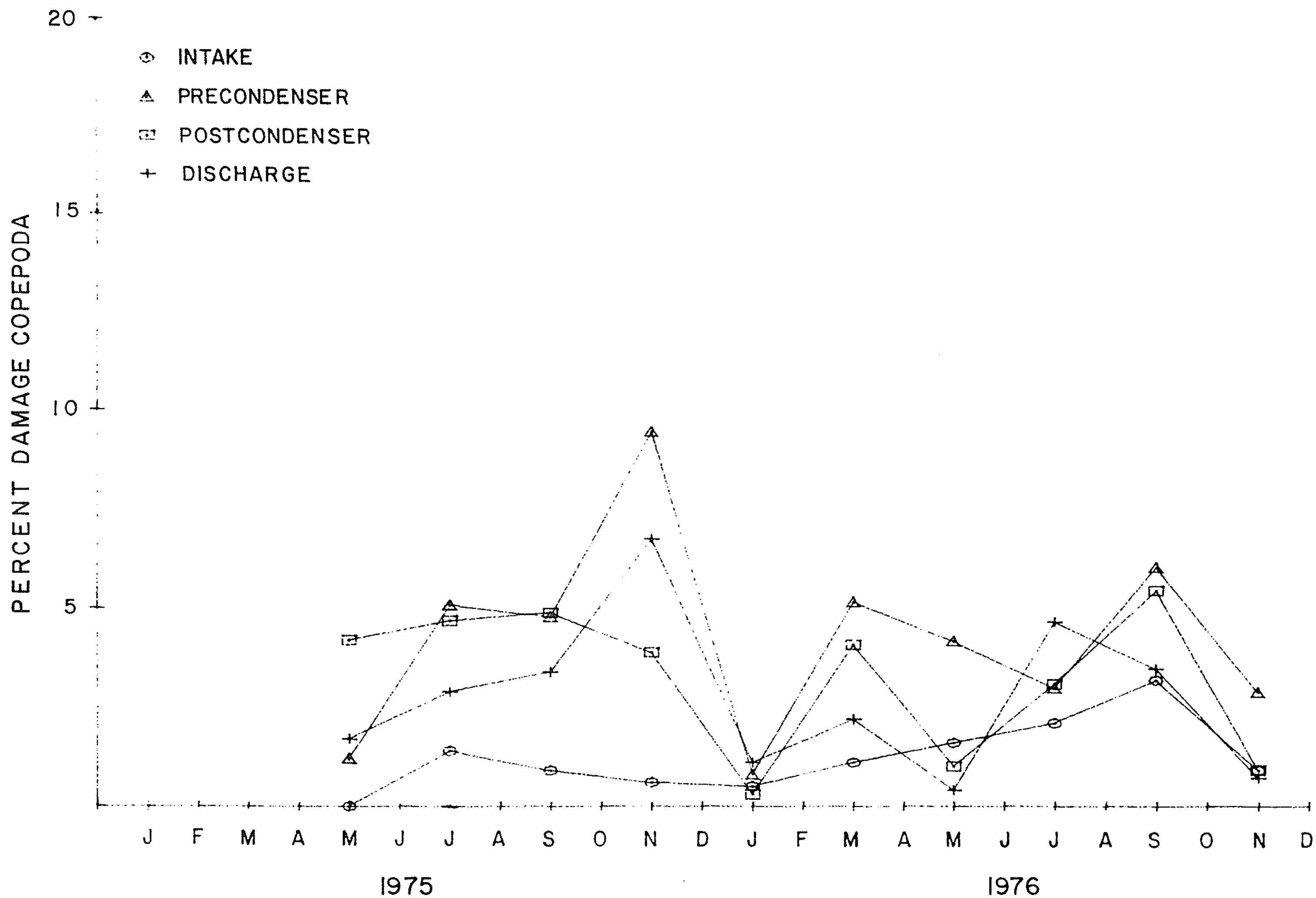


Figure 6-11. Percent damage for Copepoda at four sampling locations. Values are means of replicates.

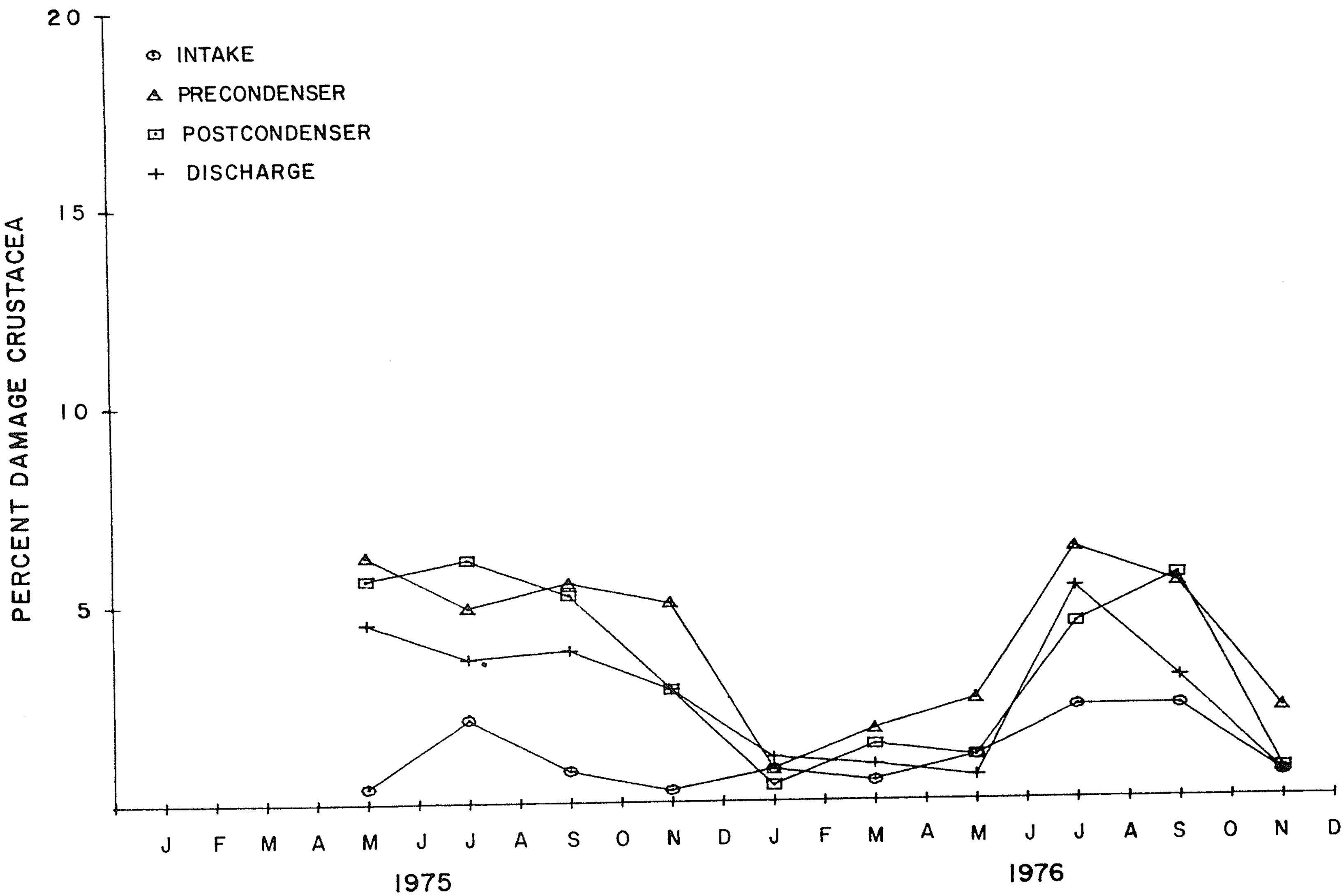


Figure 6-12. Percent damage of total Crustacea at four sampling locations. Values are means of replicates.

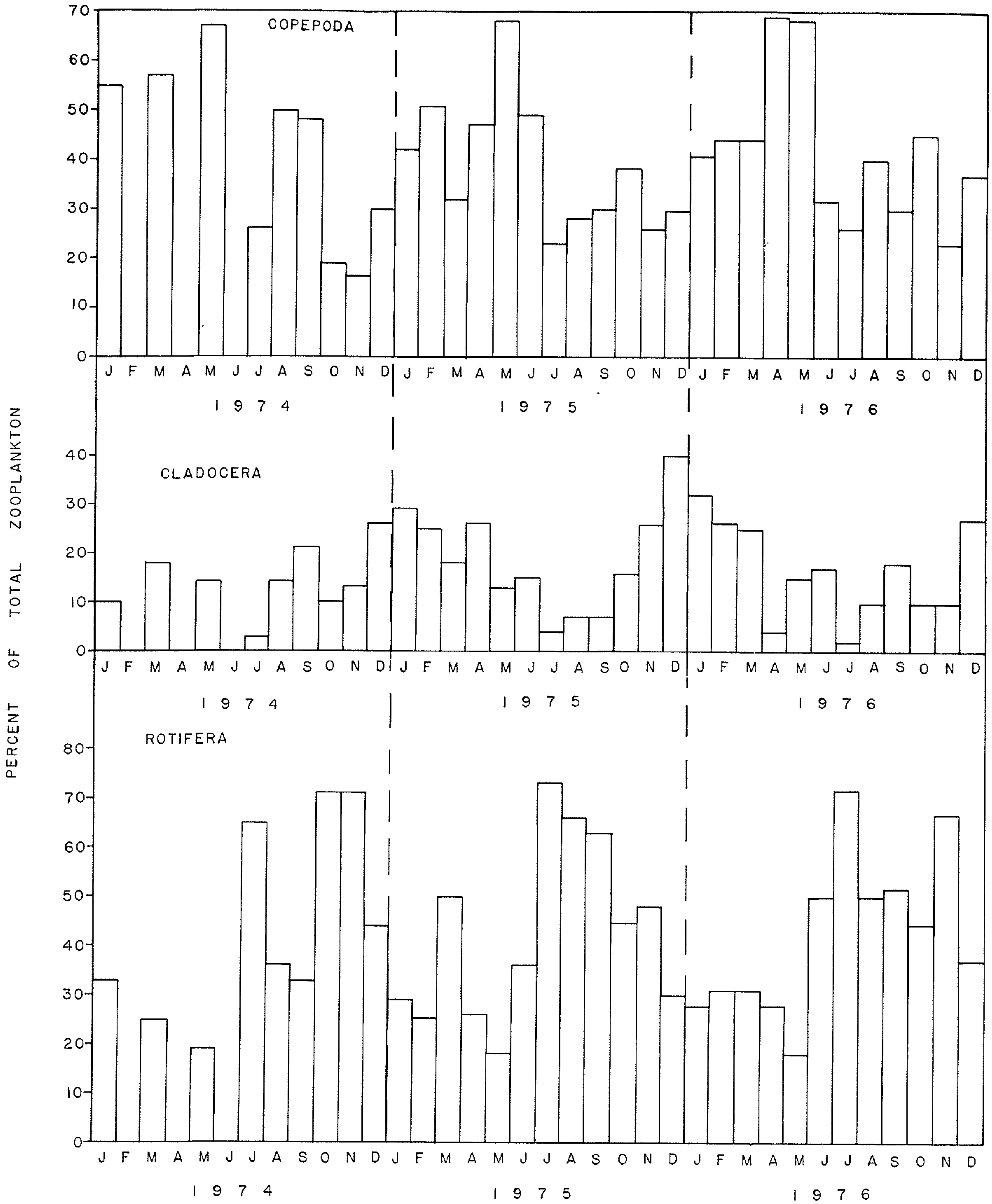
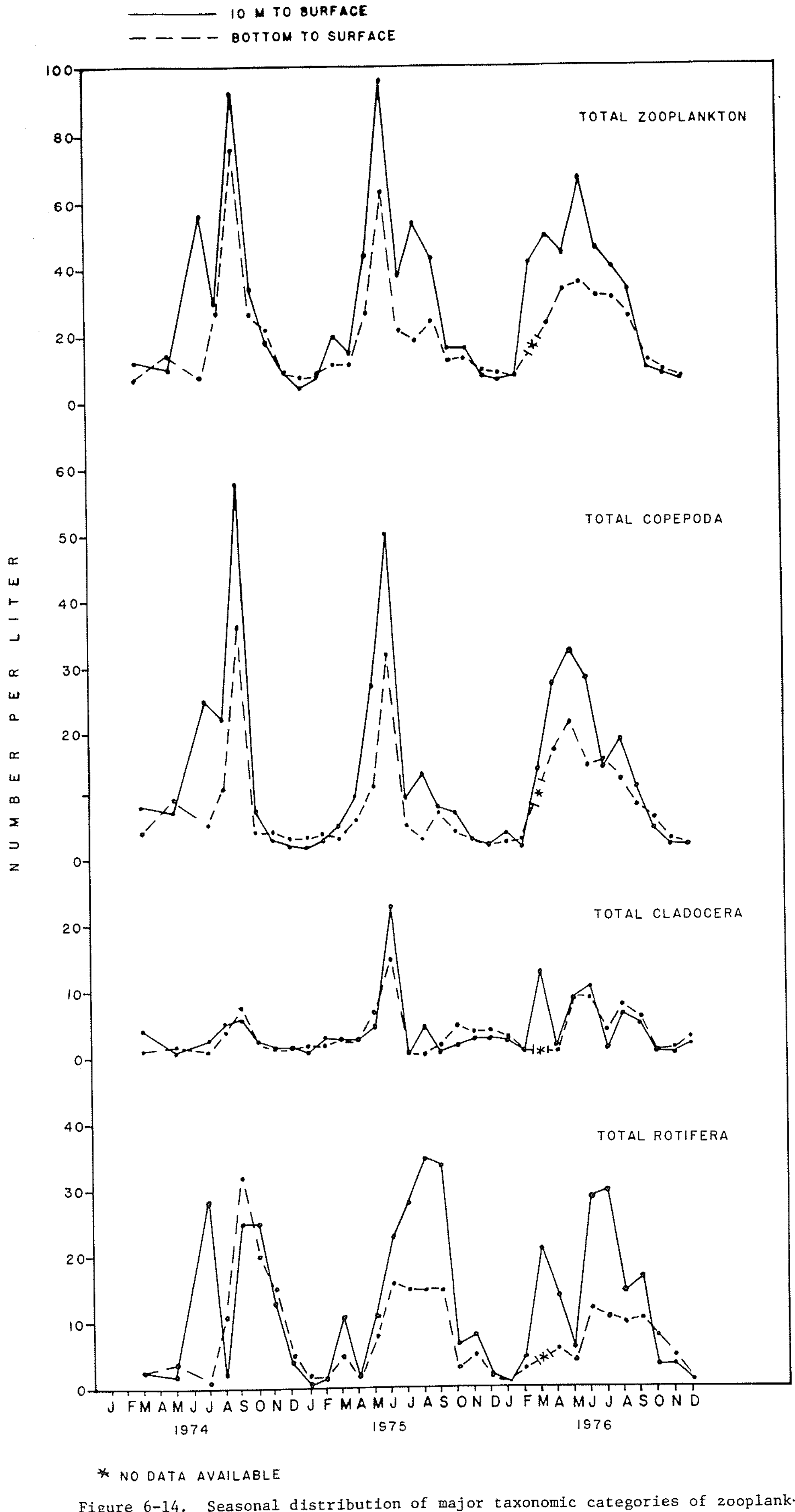


Figure 6-13. Relative composition of zooplankton in Lake Keowee, 1974 through 1976. All values calculated as a grand mean of reference (Locations 500.0, 501.0, 506.0), intermediate (Locations 502.0, 503.0, 505.0) and discharge (Locations 508.0, 508.5, 504.0) area means.



* NO DATA AVAILABLE

Figure 6-14. Seasonal distribution of major taxonomic categories of zooplankton. Densities calculated as a grand mean of reference (Locations 500.0, 501.0, 506.0), intermediate (Locations 502.0, 503.0, 505.0) and discharge (Locations 508.0, 508.5, 504.0) area means.

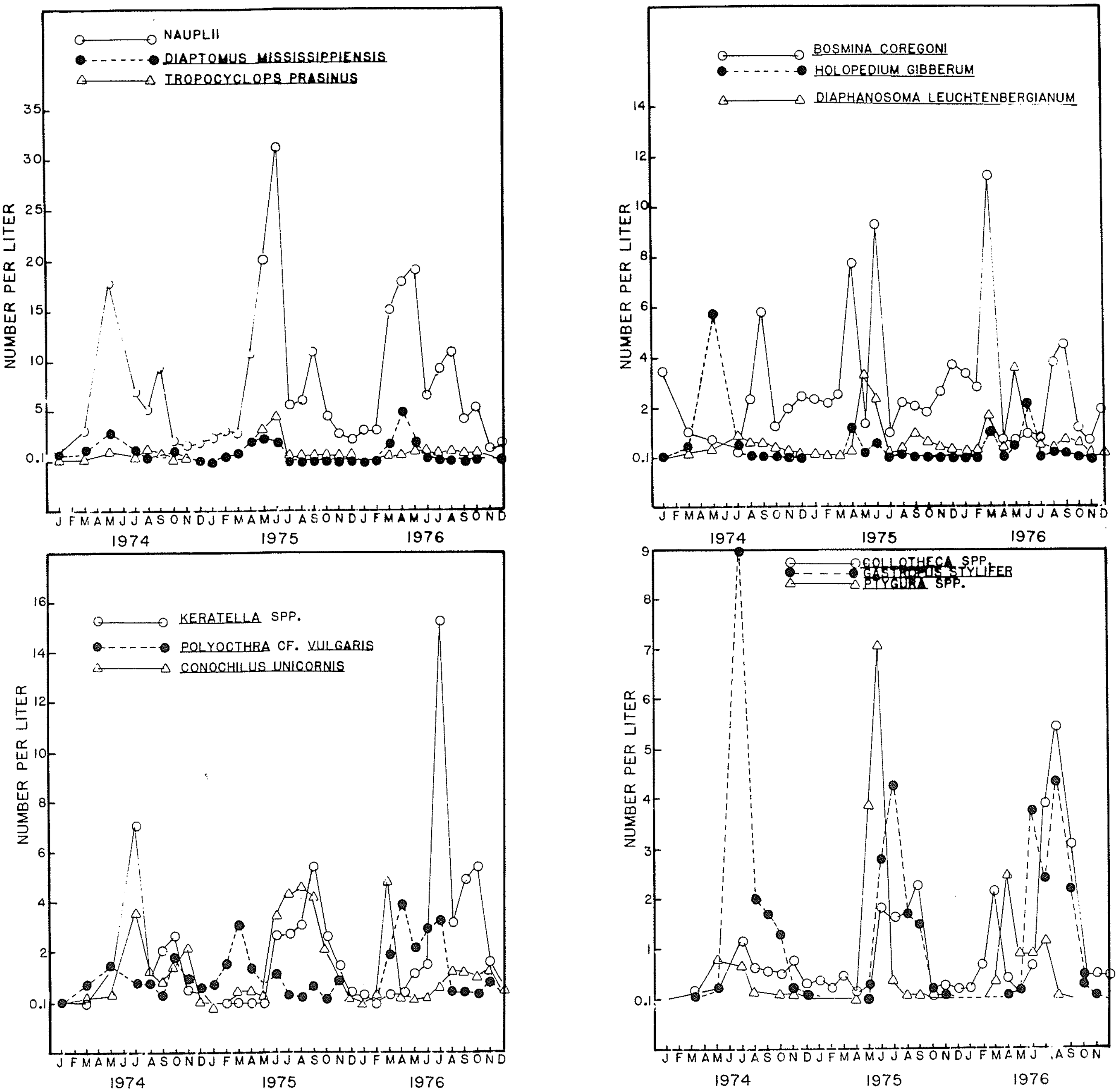
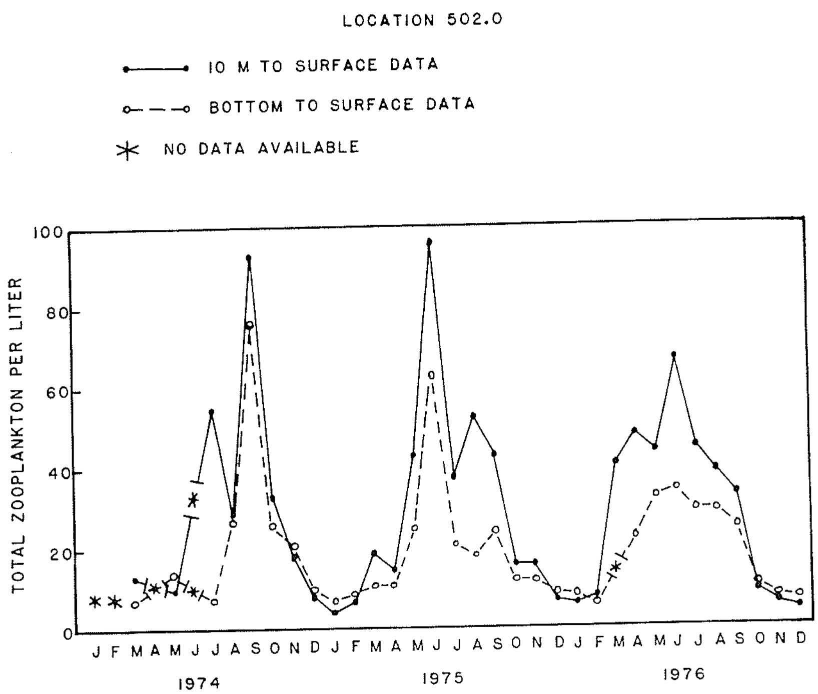


Figure 6-15. Temporal distribution from 10 m to surface of numerically dominant species and taxa from each major taxonomic group, 1974 through 1976. Densities calculated as a grand mean of reference (Locations 500.0, 501.0, 506.0), intermediate (Locations 502.0, 503.0, 505.0) and discharge (Locations 508.0, 508.5, 504.0) area menas.



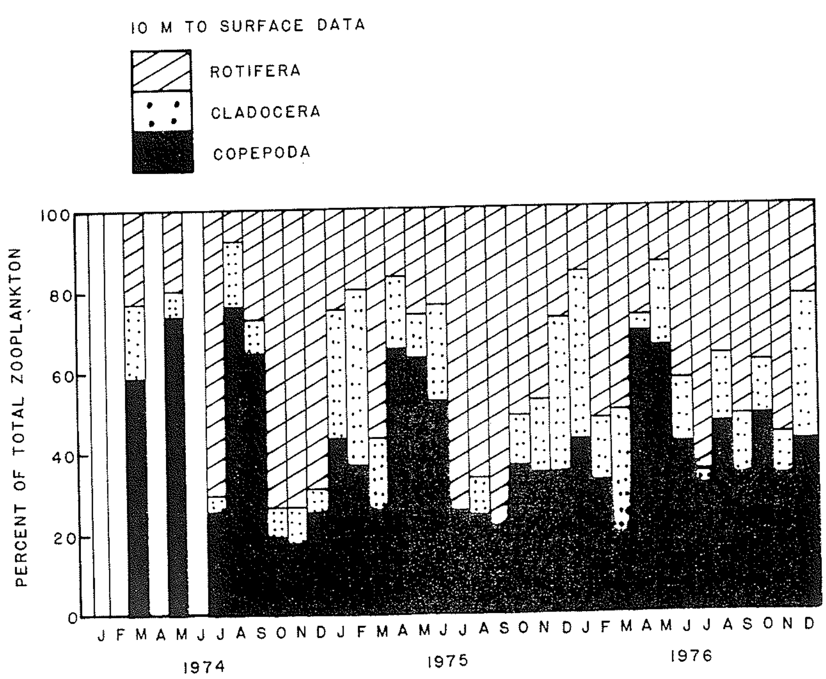
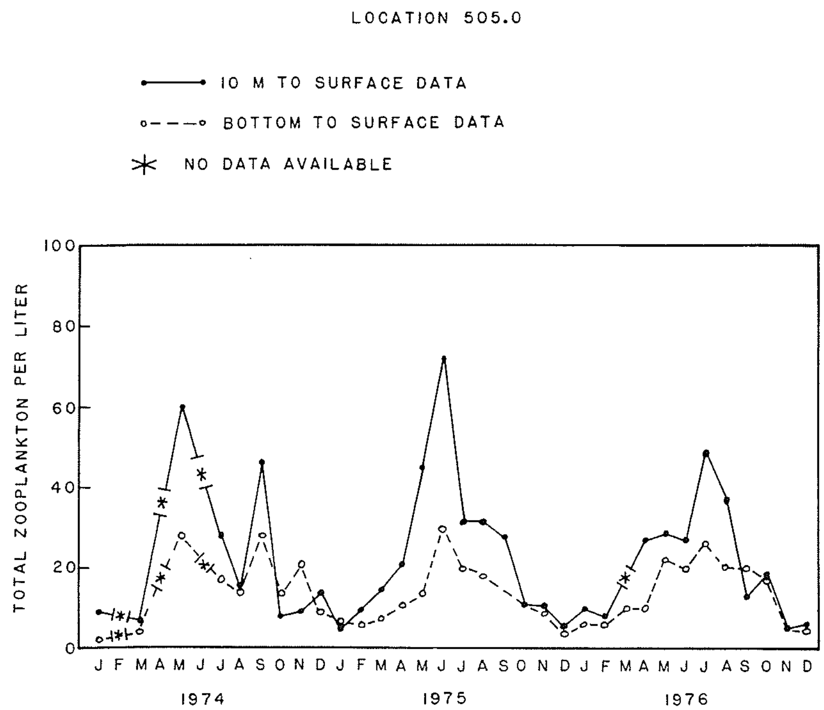


Figure 6-16. Temporal distribution from 10 m to surface and taxonomic composition of zooplankton at Location 502.0 (lakeside of the skimmer wall), 1974 through 1976.



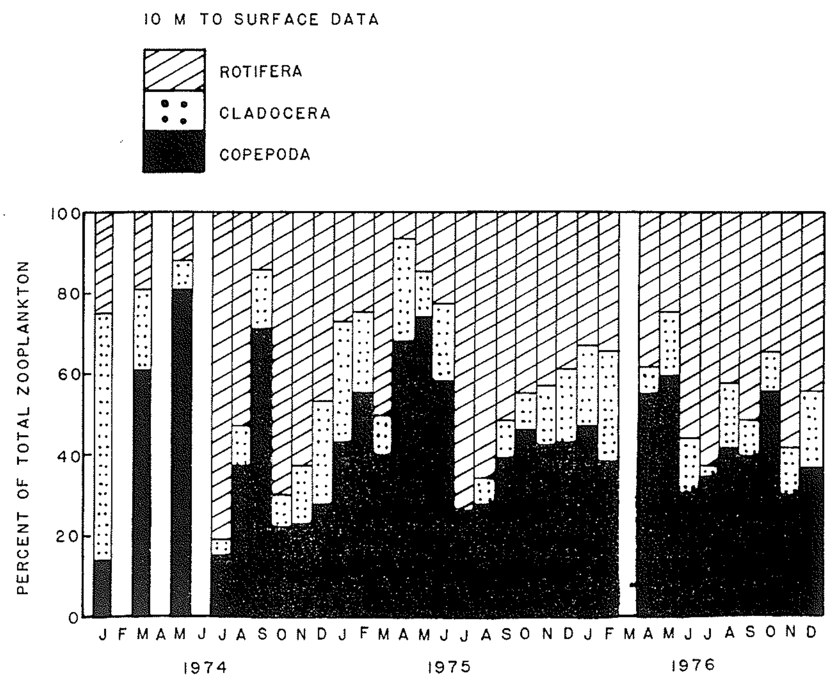
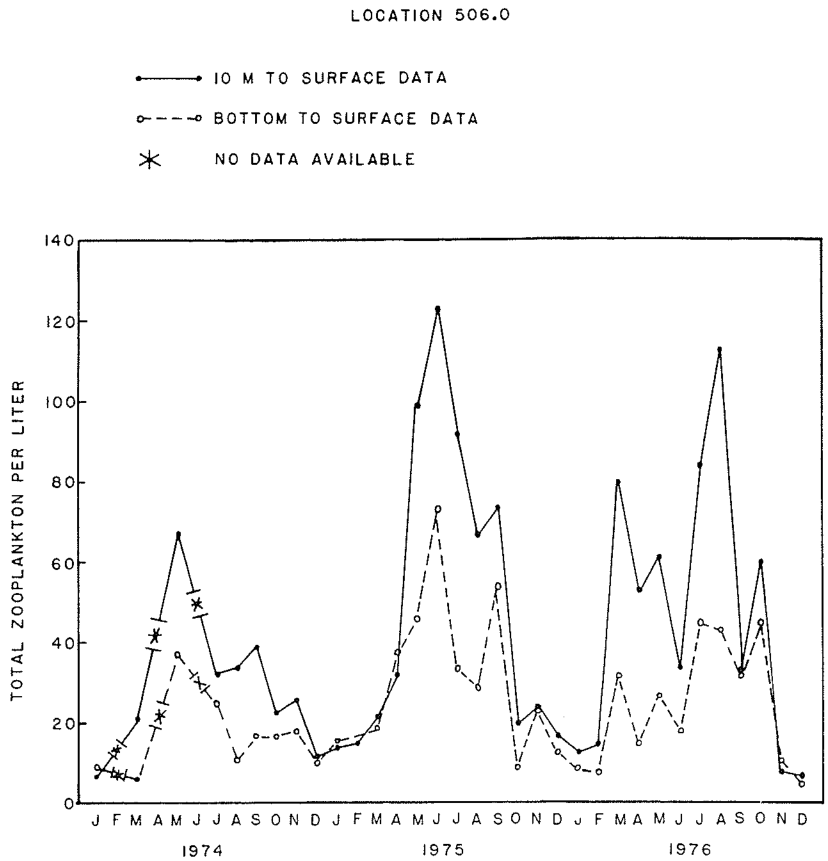


Figure 6-17. Temporal distribution from 10 m to surface and taxonomic composition of zooplankton at Location 505.0, 1974 through 1976.



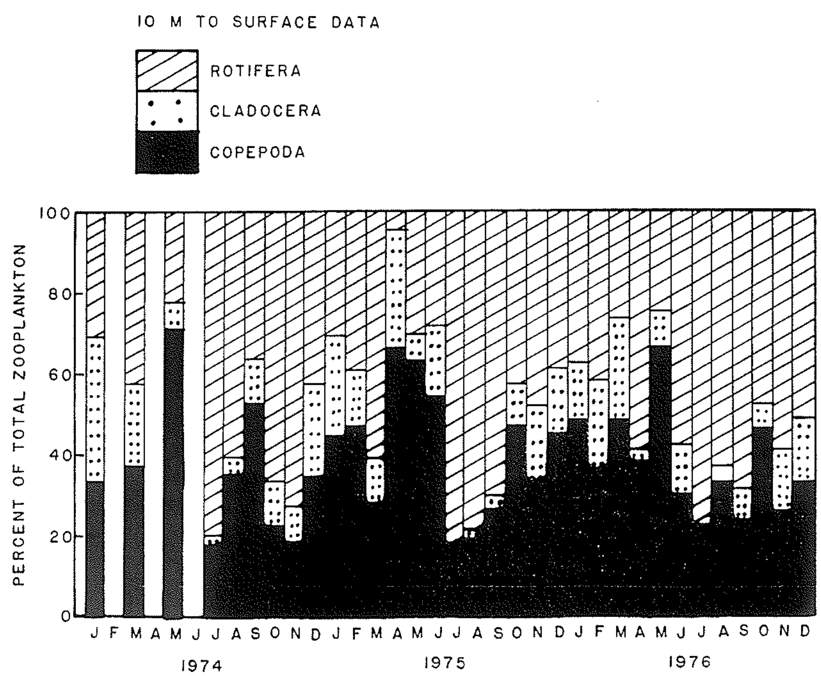
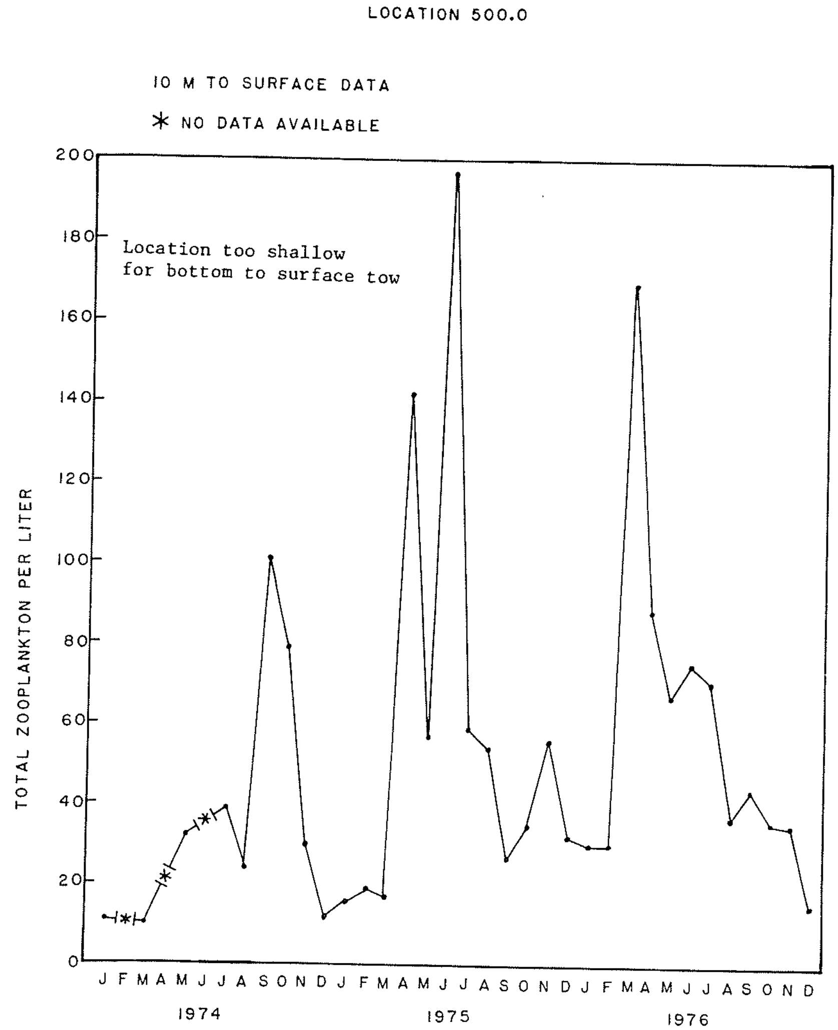


Figure 6-18. Temporal distribution from 10 m to surface and taxonomic composition of zooplankton at Location 506.0, 1974 through 1976.



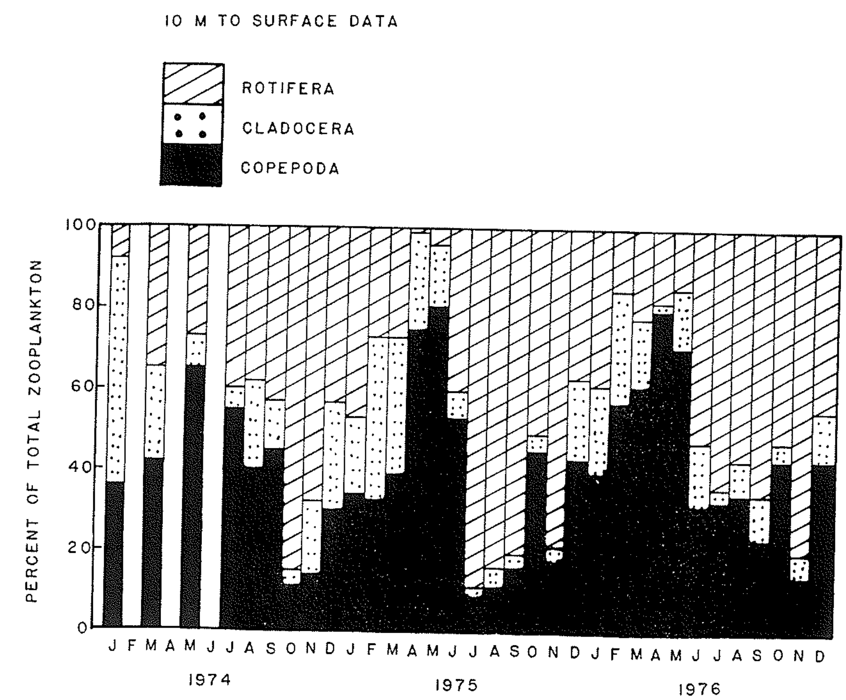
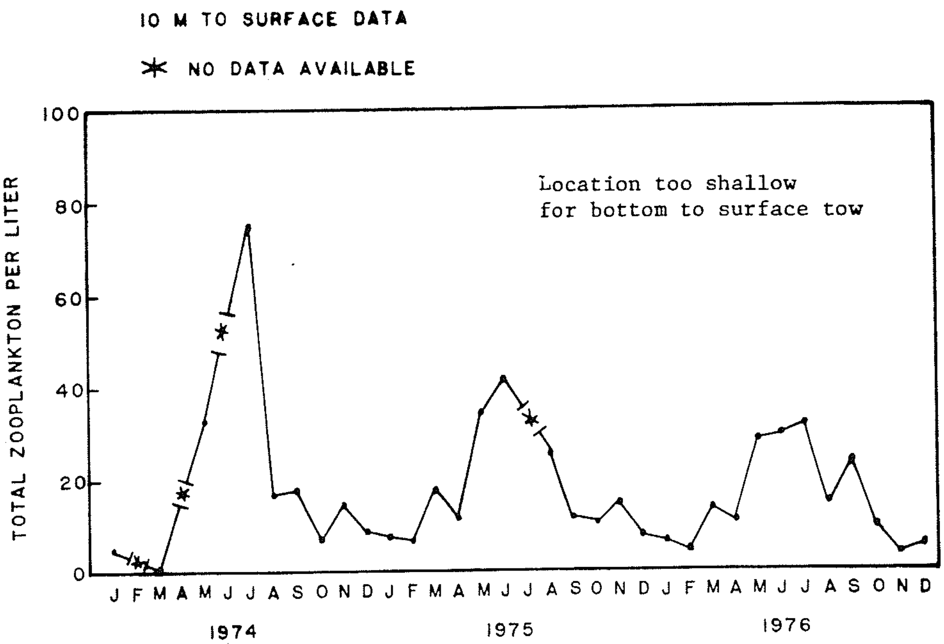


Figure 6-19. Temporal distribution from 10 m to surface and taxonomic composition of zooplankton at Location 500.0, 1974 through 1976.

LOCATION 508.5



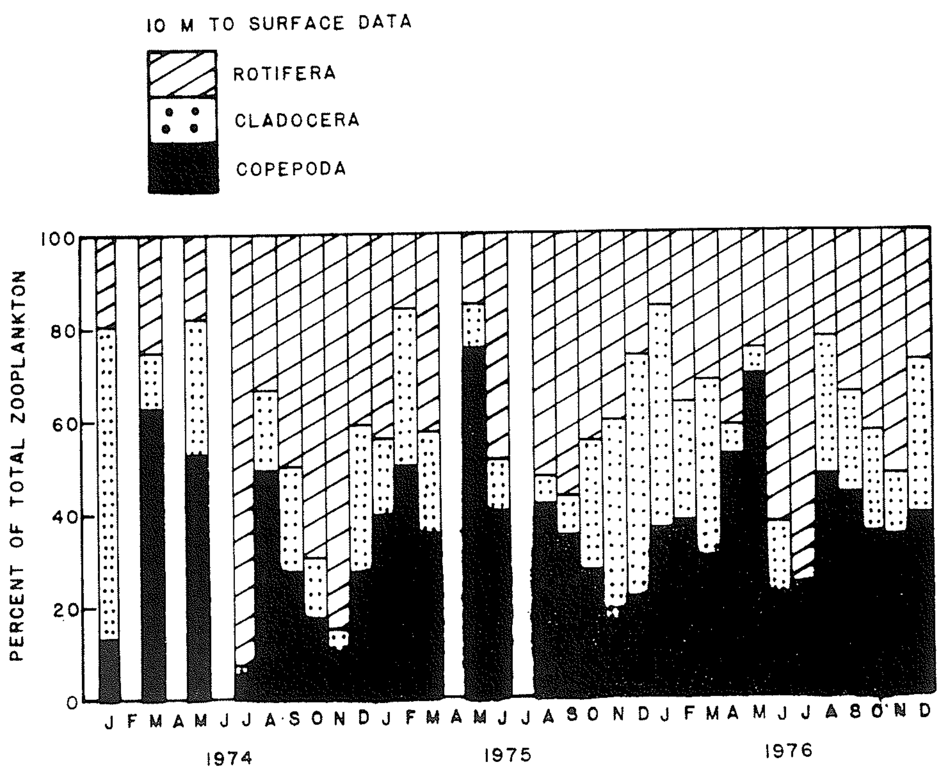


Figure 6-20. Temporal distribution from 10 m to surface and taxonomic composition of zooplankton at Location 508.5, 1974 through 1976.

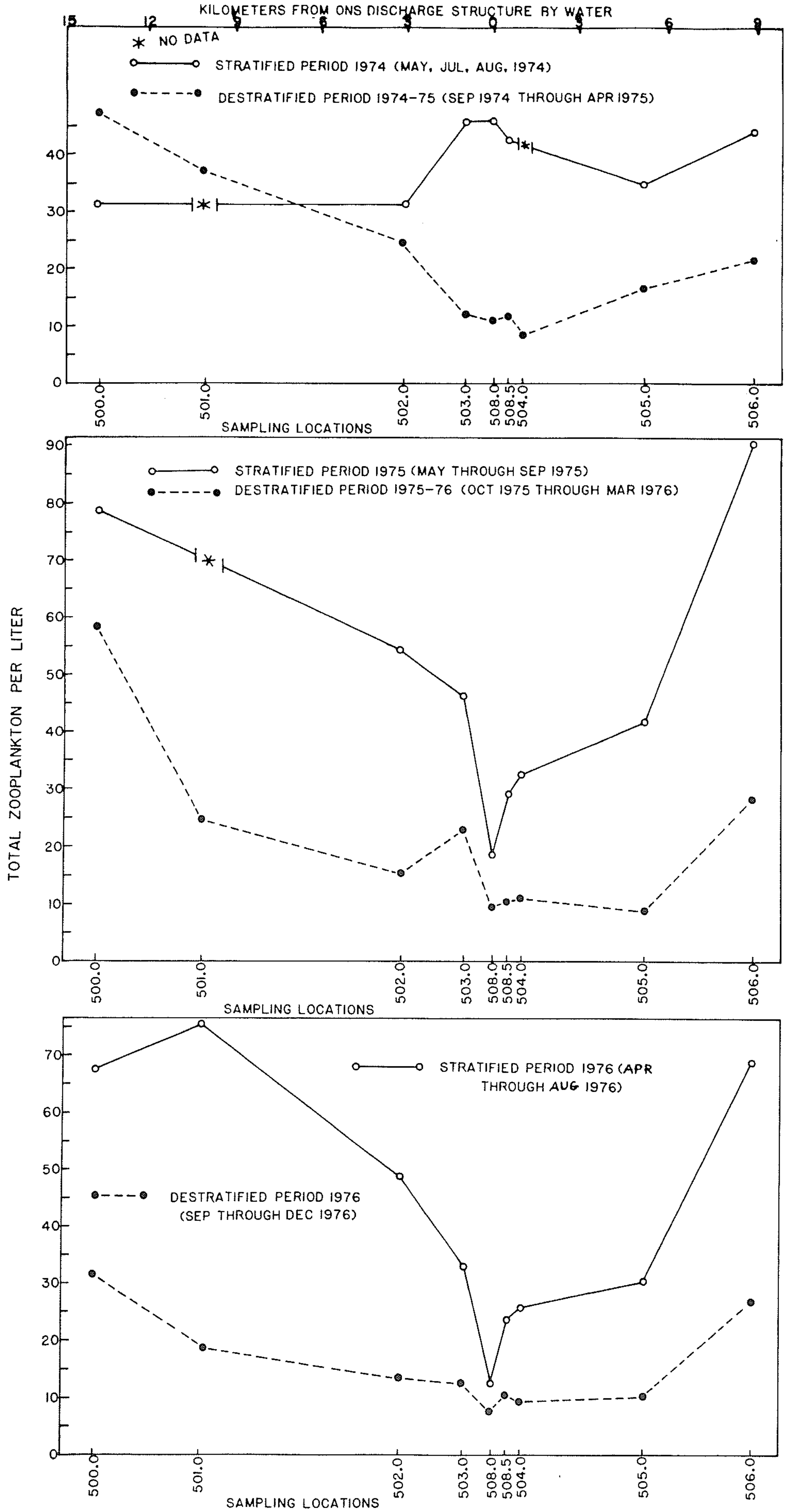


Figure 6-21. Total Zooplankton distribution (10 m to surface) among locations for stratified and destratified periods of 1974 through 1976. Densities were calculated as a mean of the monthly densities included in a given thermal period.

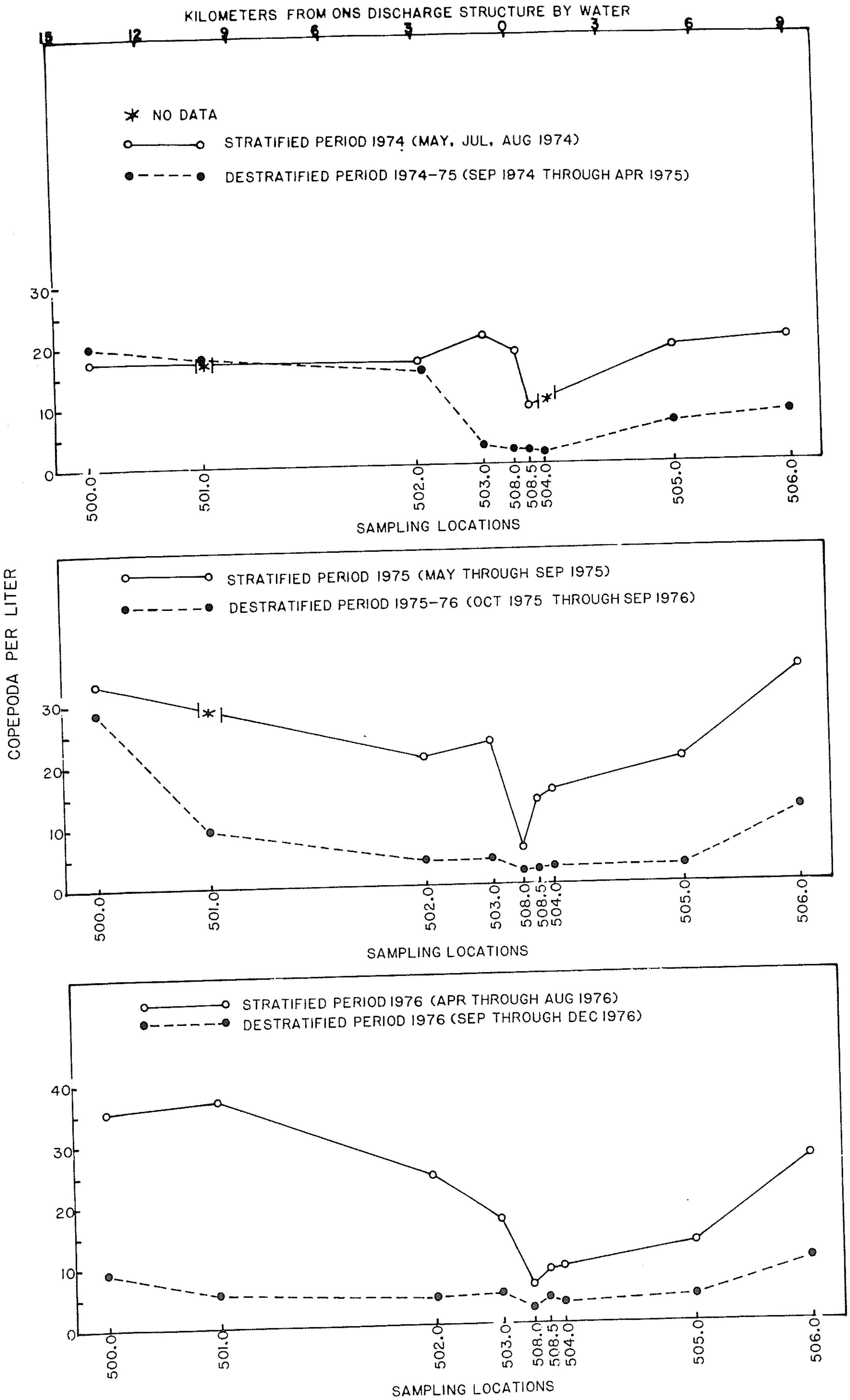


Figure 6-22. Copepod distribution (10 m to surface) among locations for stratified and destratified periods of 1974 through 1976. Densities were calculated as a mean of the monthly densities included in a given period.

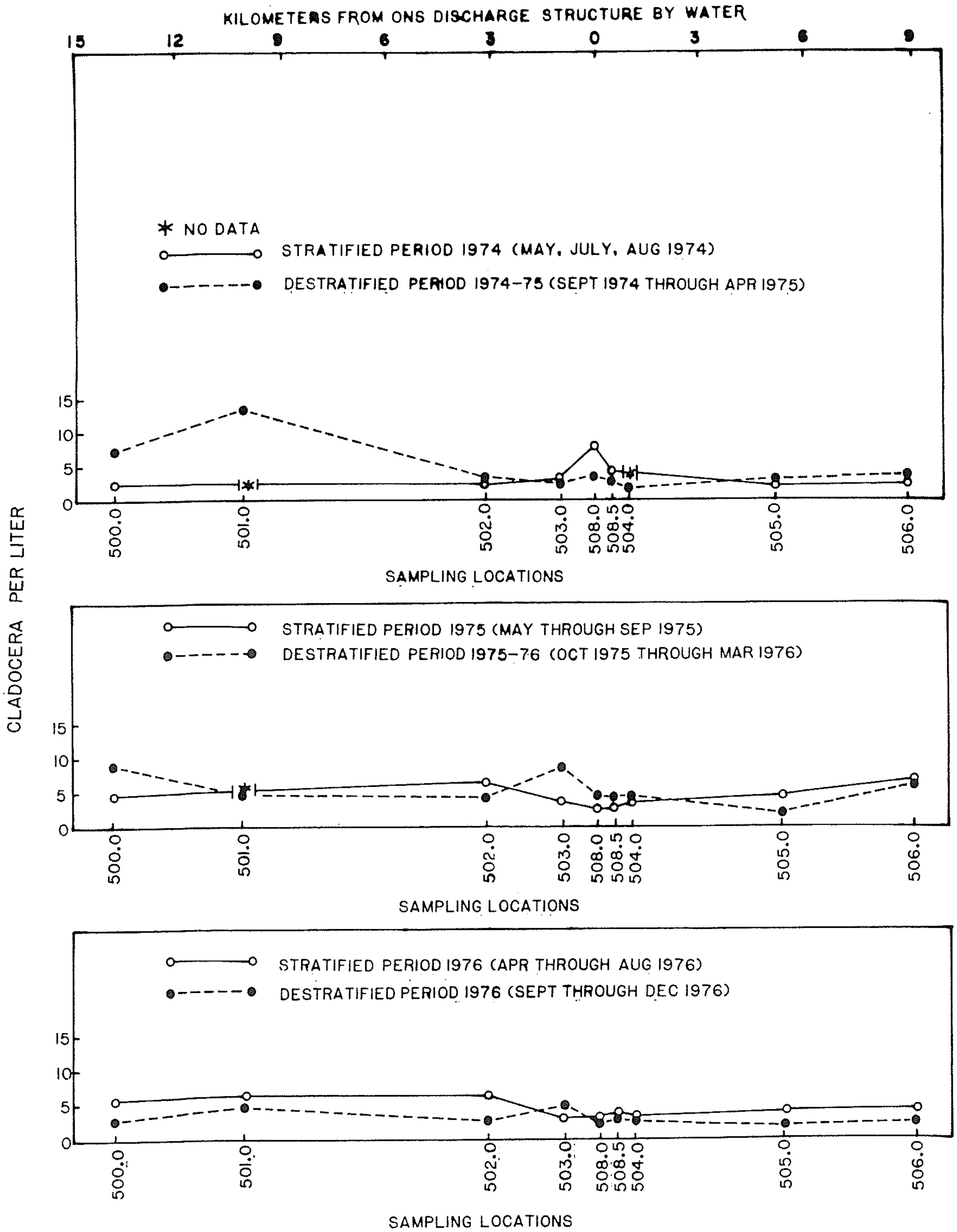


Figure 6-23. Cladoceran distribution (10 m to surface) among locations for stratified and destratified periods of 1974 through 1976. Densities were calculated as a mean of the monthly densities included in a given thermal period.

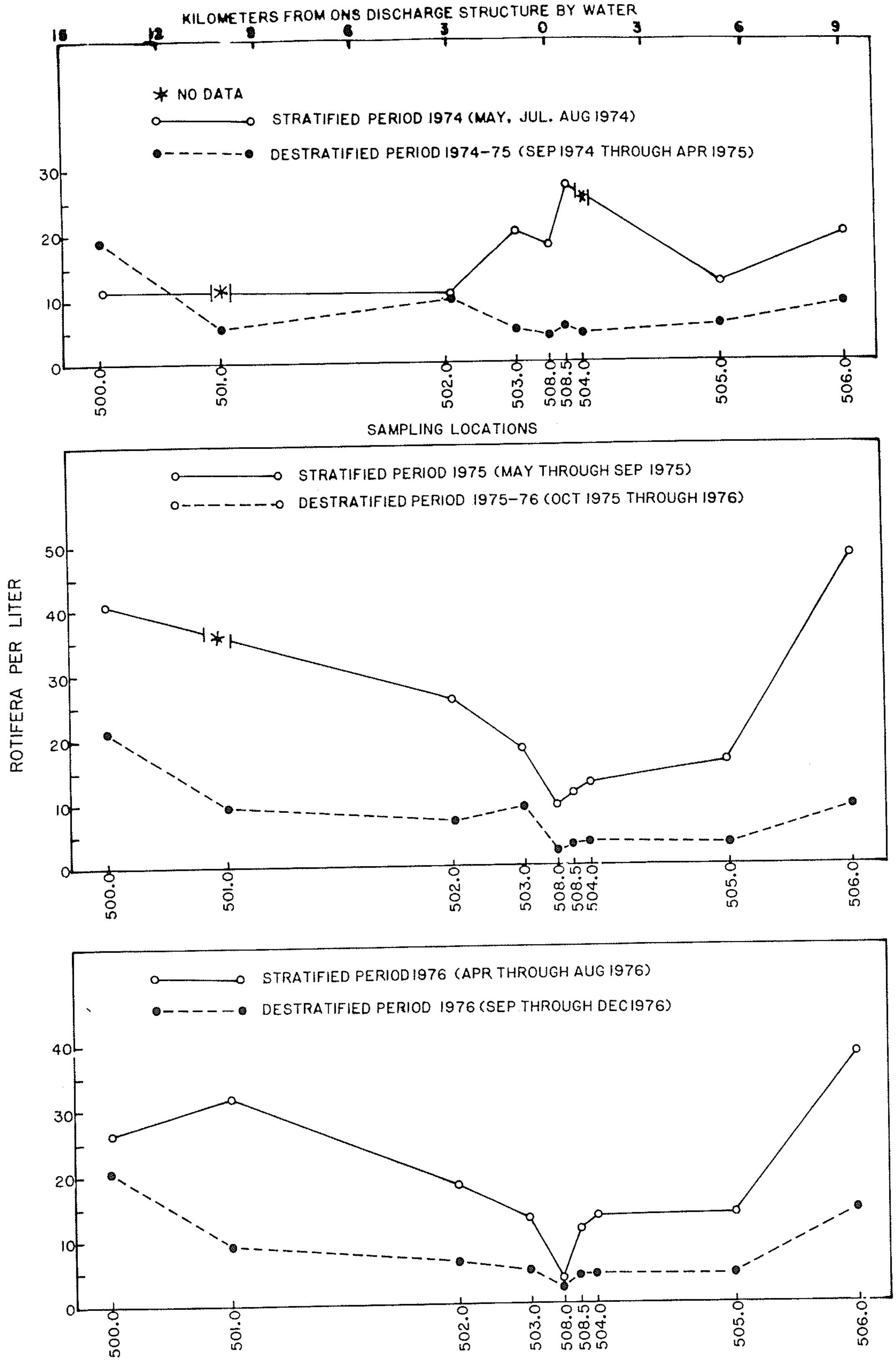


Figure 6-24. Rotifer distribution (10 m to surface) among locations for stratified and destratified periods of 1974 through 1976. Densities were calculated as a mean of the monthly densities included in a given thermal period.

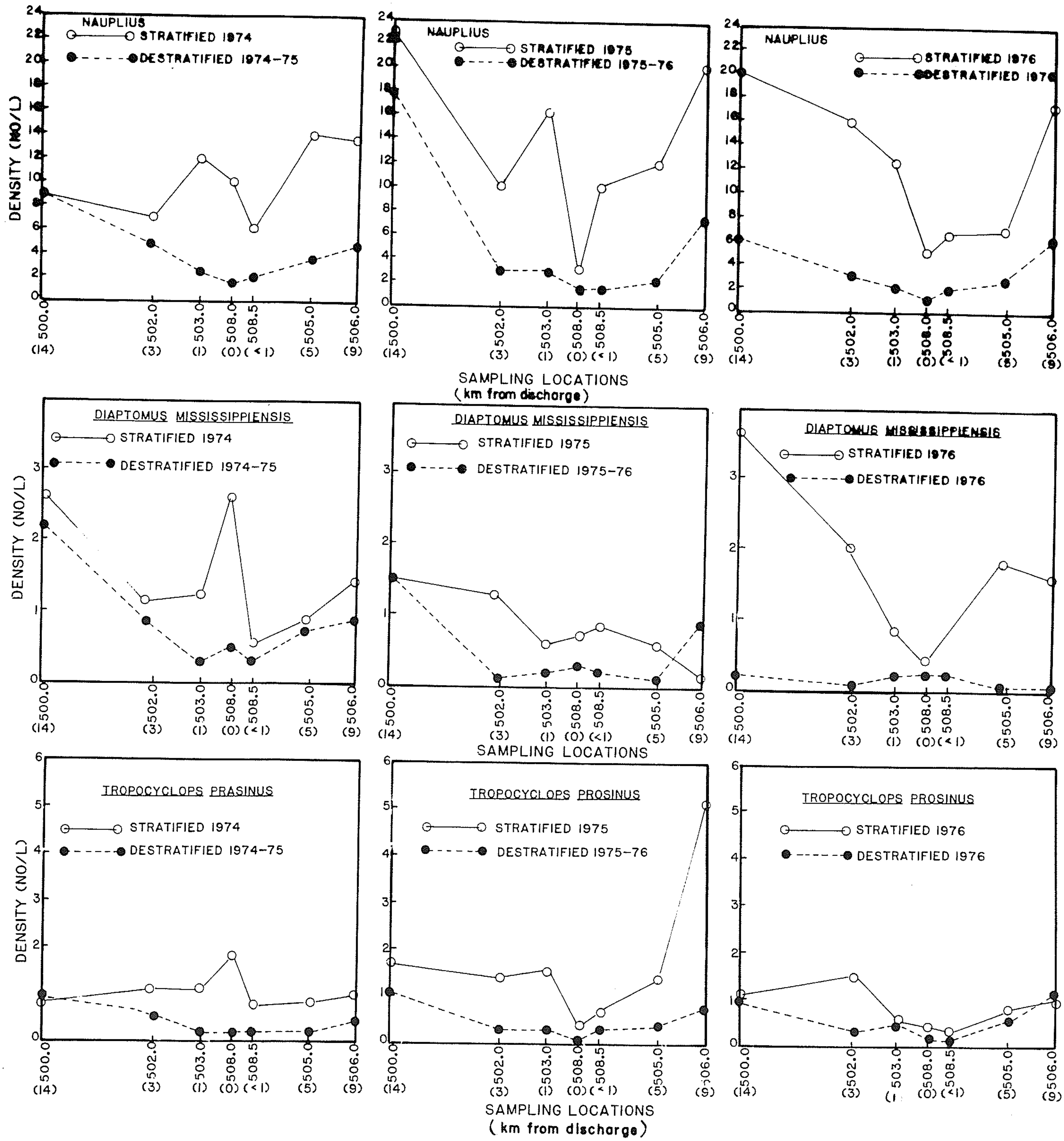


Figure 6-25. Spatial distribution (10 m to surface) among locations for numerically prevalent copepod taxa for stratified and destratified periods of 1974 through 1976. Densities were calculated as a mean of the monthly densities included in a given thermal period.

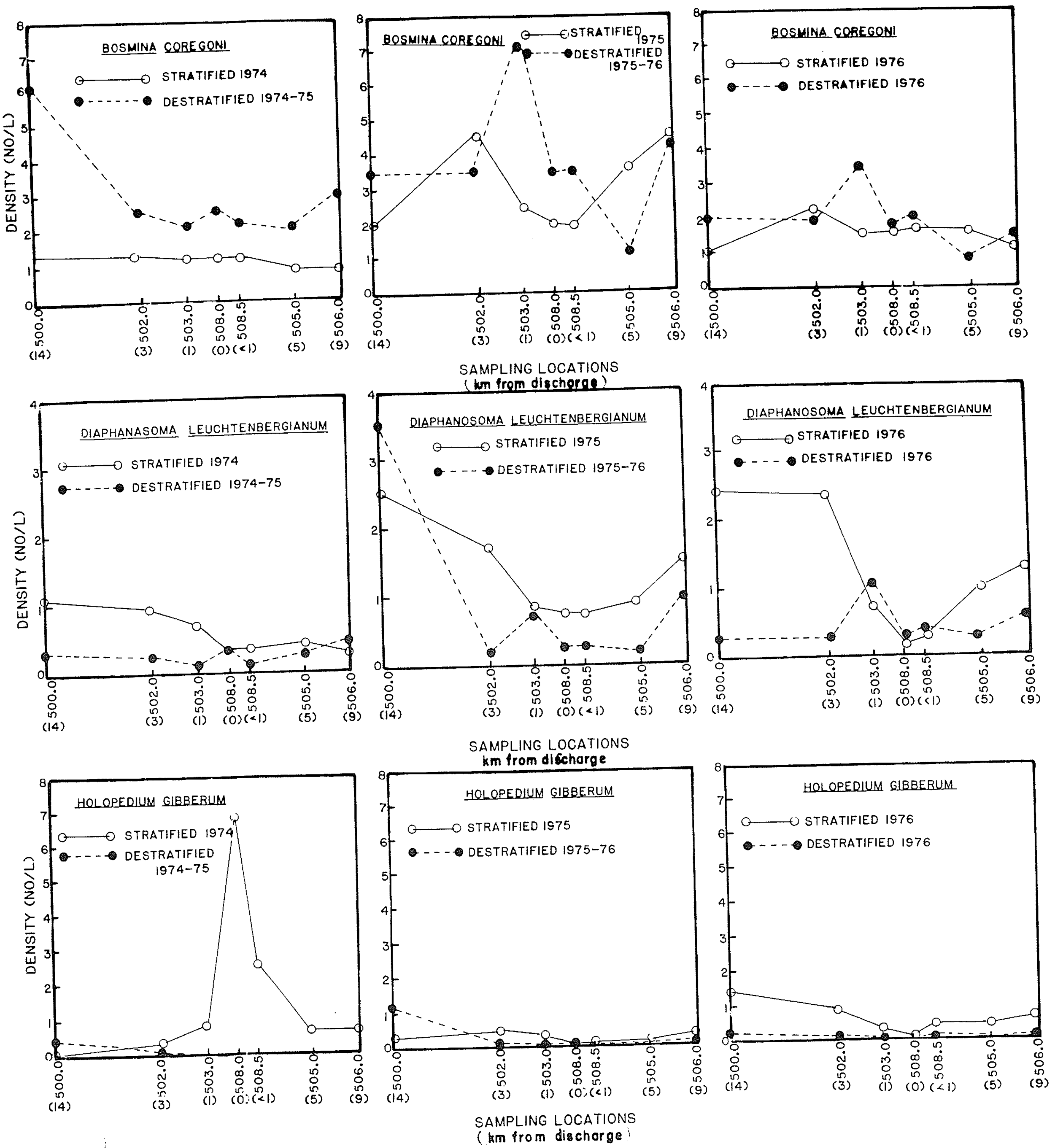


Figure 6-26. Spatial distribution (10 m surface) among locations for numerically prevalent cladoceran taxa for stratified and destratified periods of 1974 through 1976. Densities were calculated as a mean of the monthly densities included in a given thermal period.

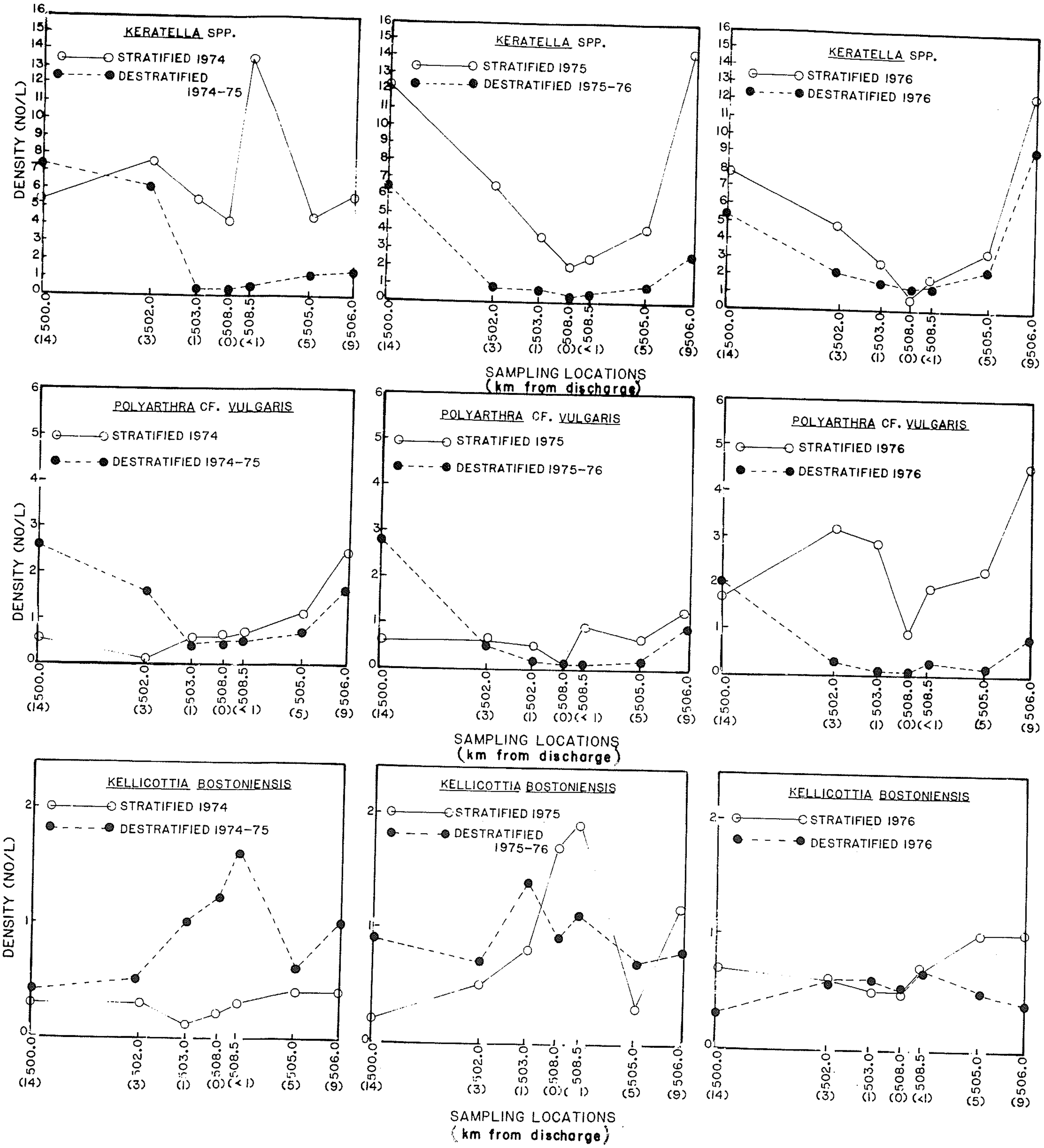


Figure 6-27. Spatial distribution (10 m to surface) among locations for numerically prevalent rotifer taxa for stratified and destratified periods of 1974 through 1976. Densities were calculated as a mean of the monthly densities included in a given thermal period.

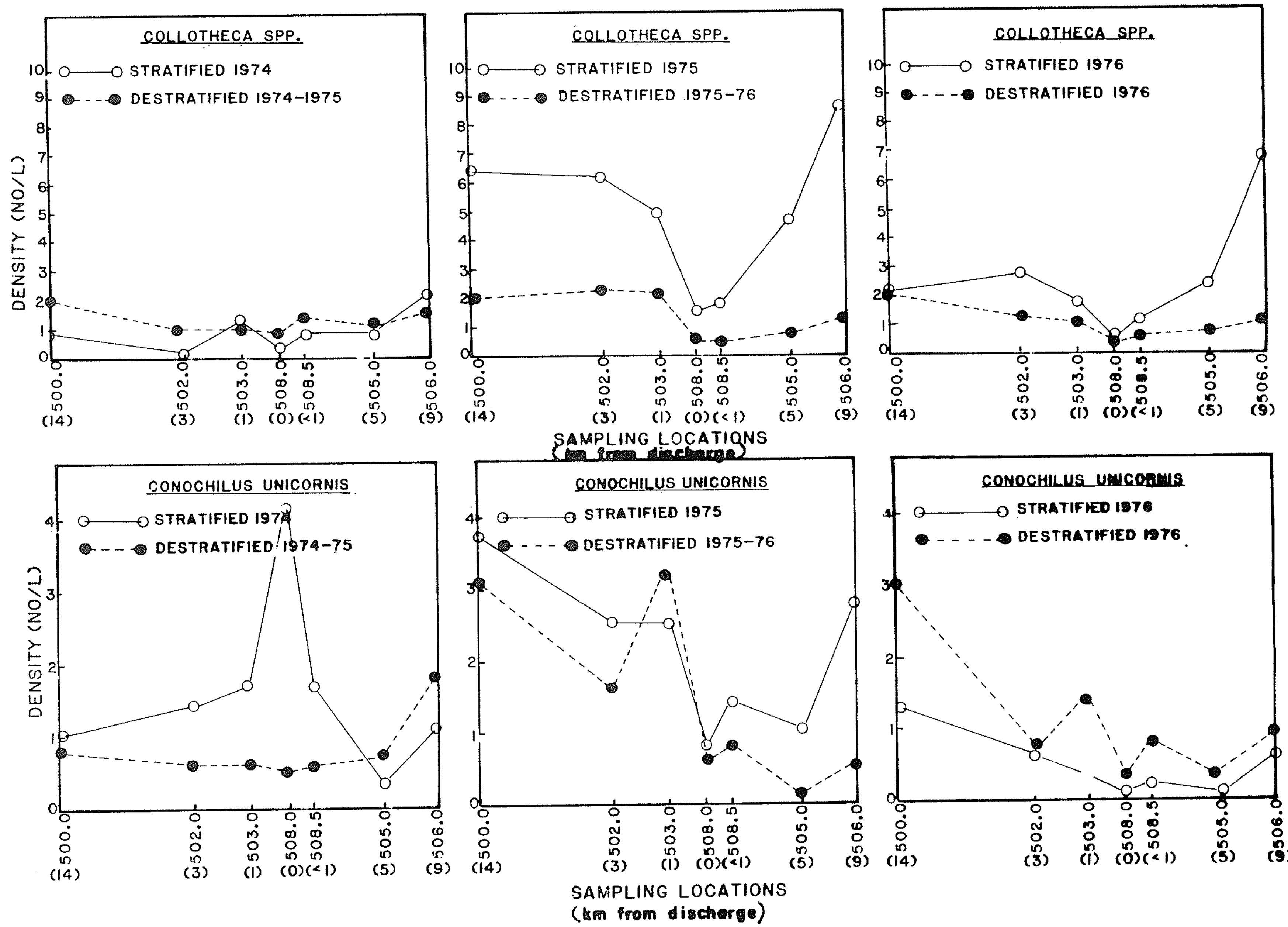


Figure 6-28. Spatial distribution (10 m to surface) among locations for numerically prevalent rotifer taxa for stratified and destratified periods of 1974 through 1976. Densities were calculated as a mean of the monthly densities included in a given thermal period.

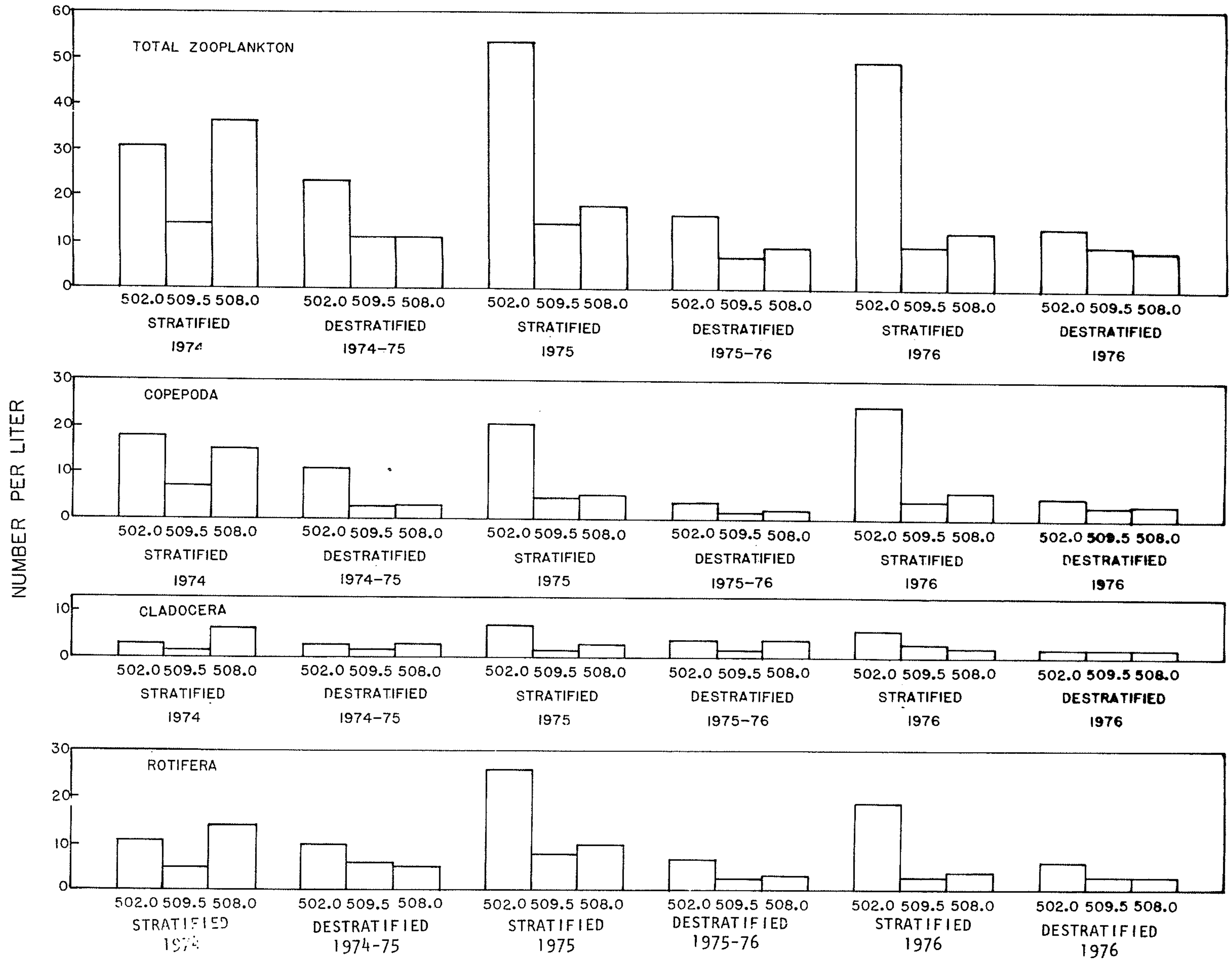


Figure 6-29. Zooplankton standing crop (10 m surface) lakeside of the skimmer wall (Location 502.0), in the intake canal (Location 509.5) and in the discharge cove (Location 508.0) for stratified and destratified periods of 1974 through 1976. Densities were calculated as a mean of the monthly densities included in a given thermal period.

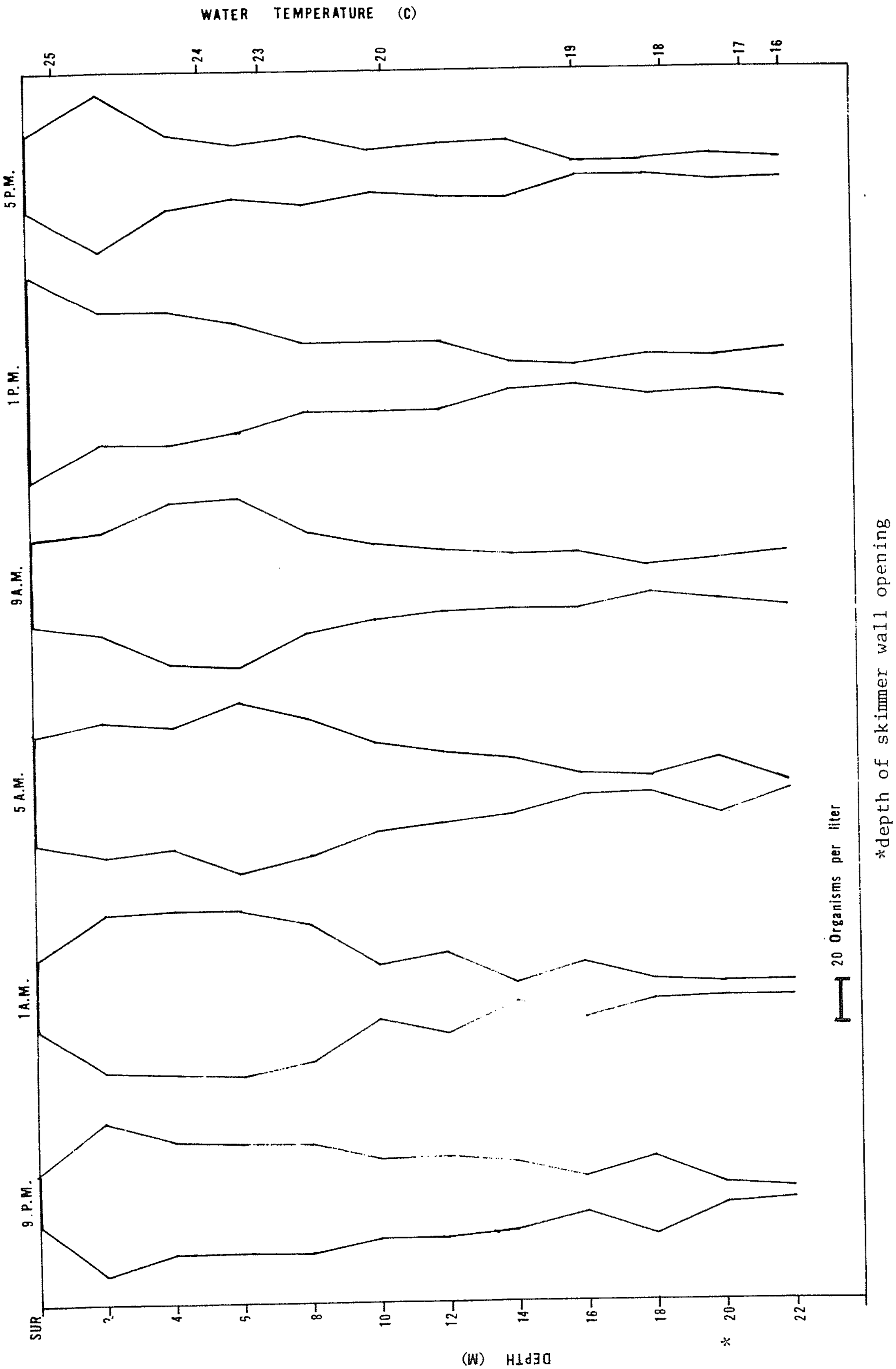


Figure 6-30. Vertical distribution of the combined immature Copepoda (nauplius, calanoid and cyclopoid copepodids) at six 4-hour intervals at Location 502.0 (lakeside of the skimmer wall). June 10 and 11 1975 diel study. Lake Keowee, South Carolina.

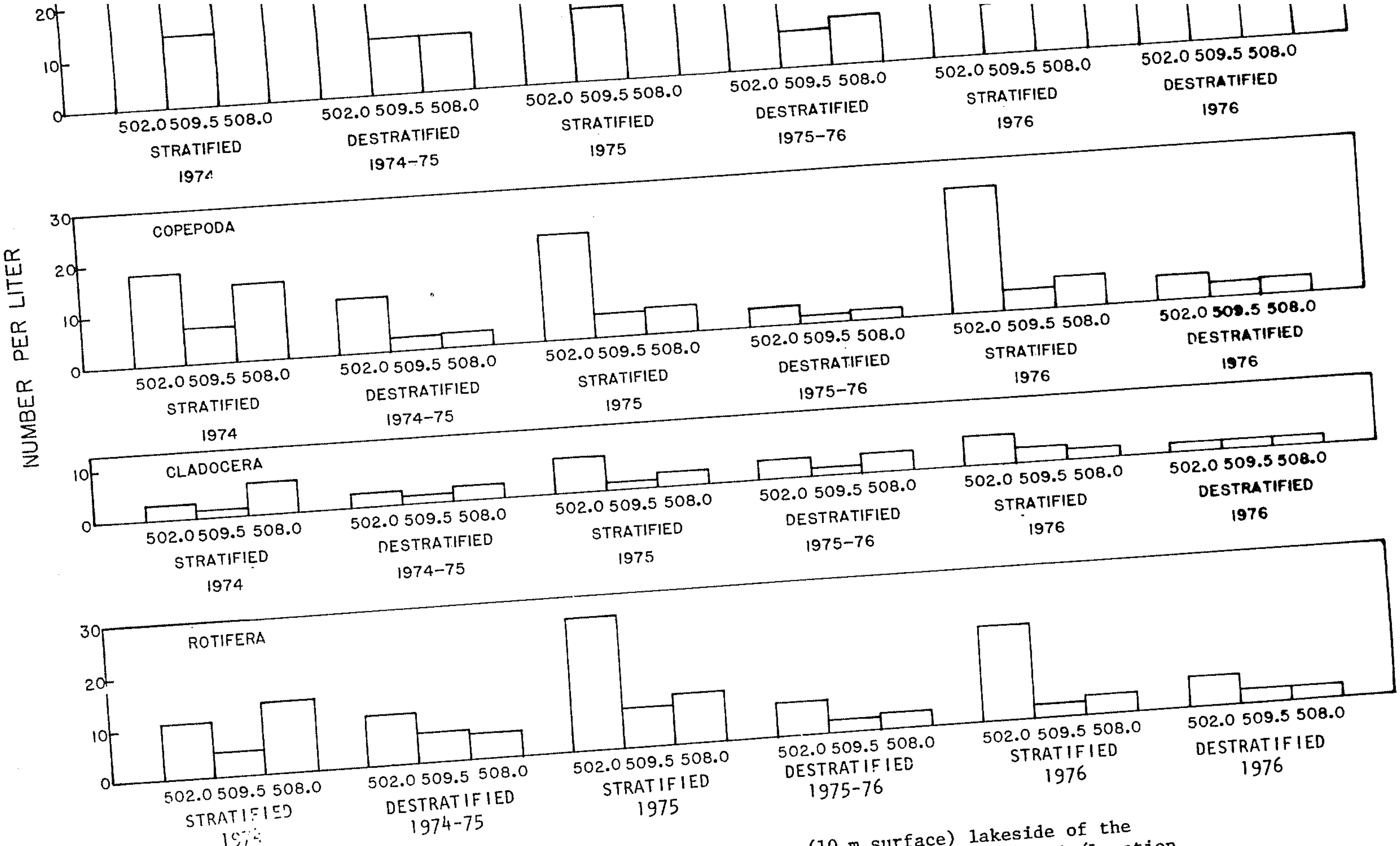
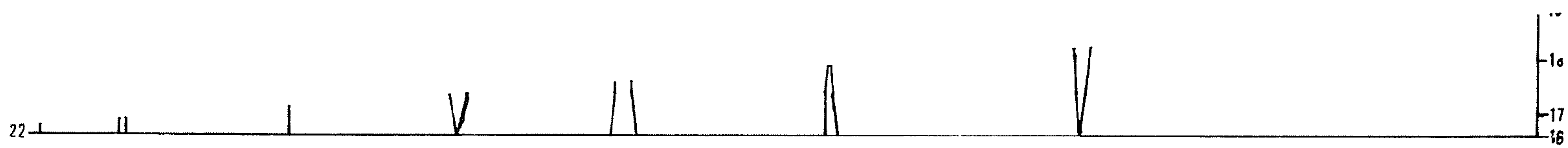


Figure 6-29. Zooplankton standing crop (10 m surface) lakeside of the skimmer wall (Location 502.0), in the intake canal (Location 509.5) and in the discharge cove (Location 508.0) for stratified and destratified periods of 1974 through 1976. Densities were calculated as a mean of the monthly densities included in a given thermal period.



*depth of skimmer wall opening

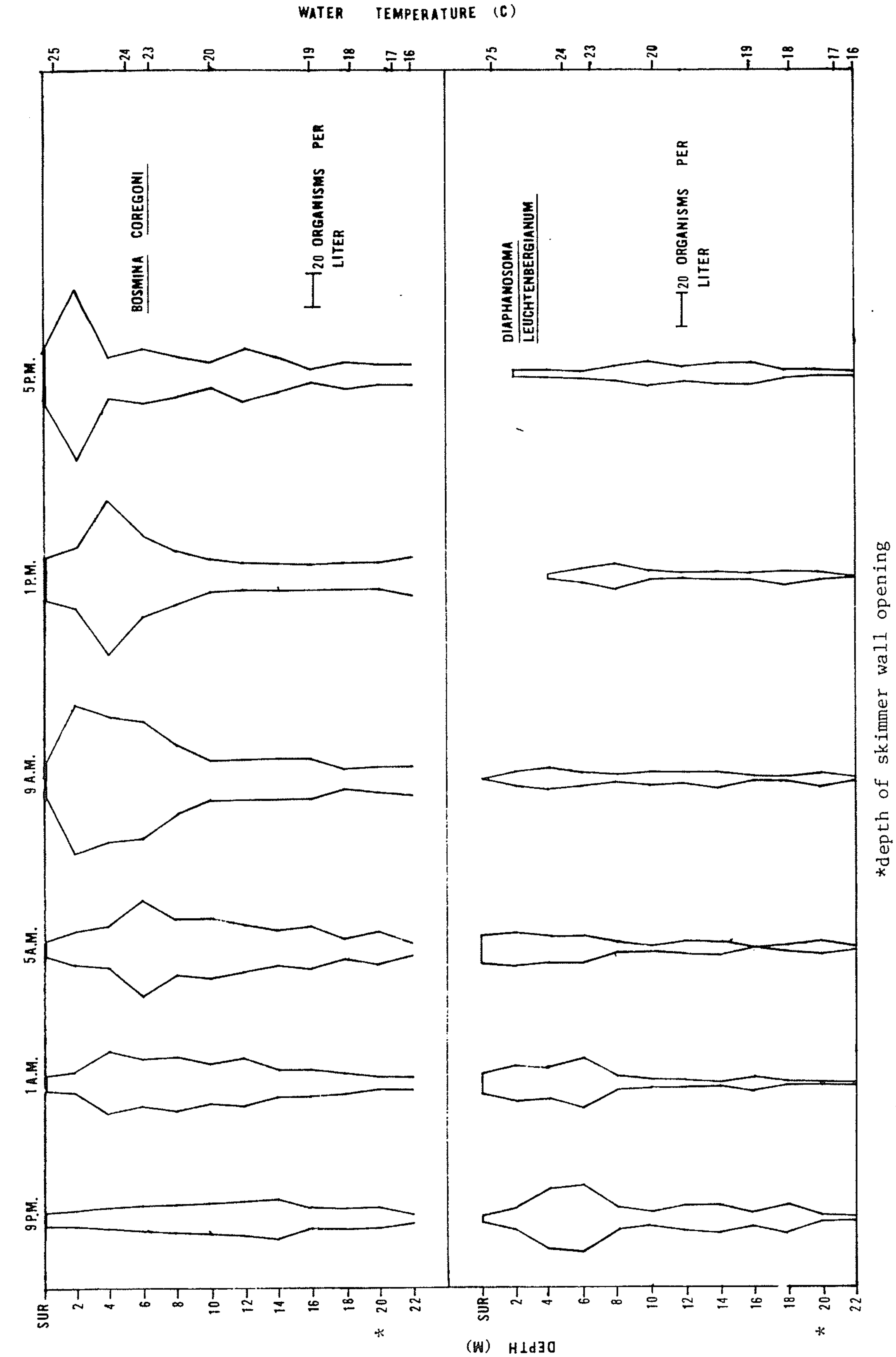


Figure 6-32. Vertical distributions of Bosmina coregoni and Diaphanosoma leuchtenbergianum at six 4-hour intervals at Location 502.0 (lakeside of the skimmer wall). June 10 and 11 1975 diel study. Lake Keowee, South Carolina.

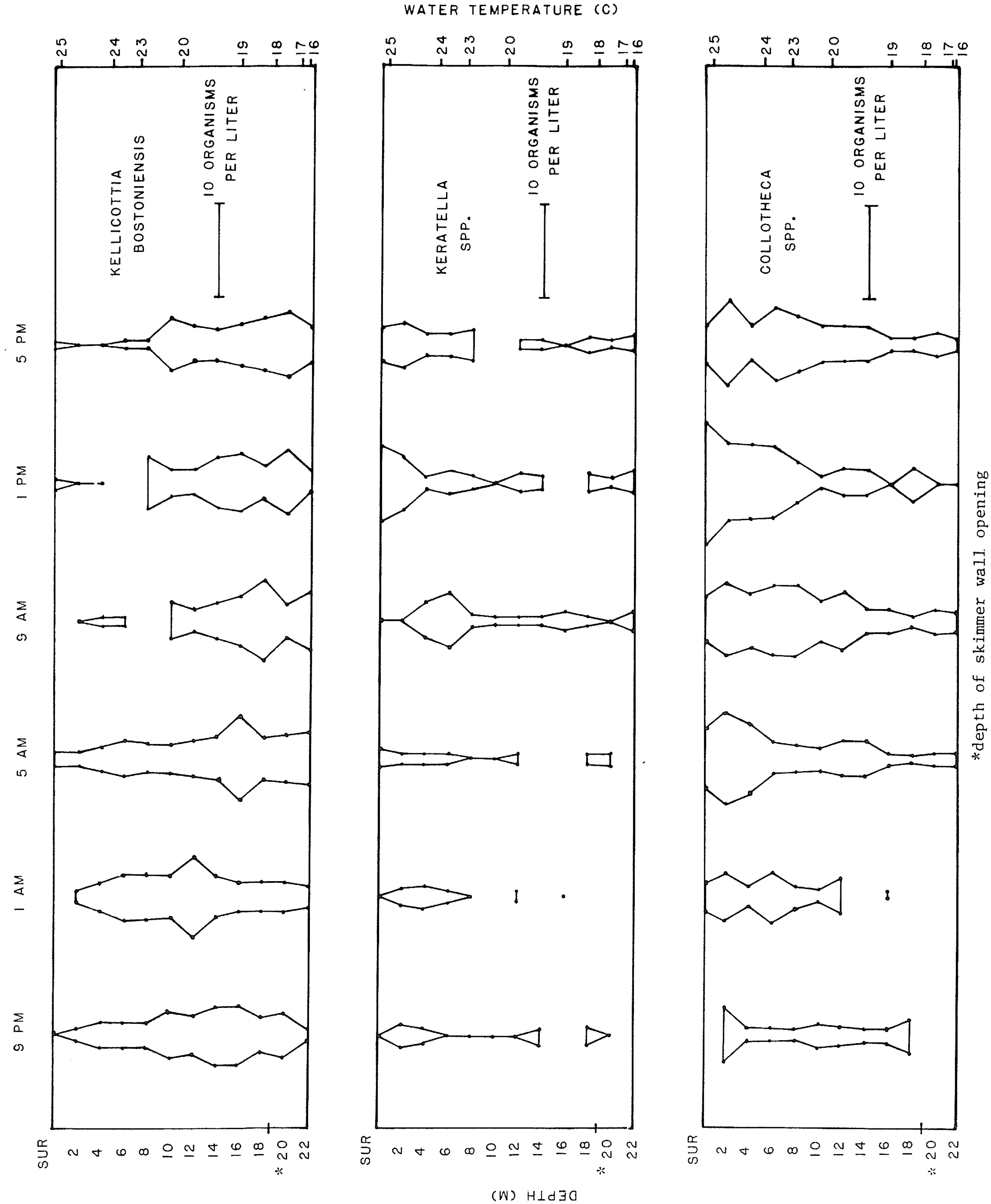


Figure 6-33. Vertical distributions of Kellicottia bostoniensis, Keratella spp, and Collotheca spp. at six 4-hour intervals at Location 502.0 (lakeside of the skimmer wall). June 10 and 11 1975 diel study. Lake Keowee, South Carolina.

CHAPTER 7. BENTHOS

INTRODUCTION

The investigation of the benthic macroinvertebrate communities in the vicinity of Oconee Nuclear Station (ONS) was initiated in February 1973 as part of Duke Power Company's aquatic surveillance program. The primary objective of this investigation is to monitor the composition, abundance, diversity, spatial and temporal distribution, and standing crop of the benthic community.

The benthos of Lake Keowee has been intensely studied since 1971, with similar findings among the many investigators. Low density and diversity were consistently reported in the area of the discharge (Langston 1973; Ryals 1975; Forsyth 1975; Hudson 1975; Sigmon et al. 1975; and Duke Power Company 1973a, b, 1974 a, b, 1975 a, b, 1976) and were attributed to substrate composition, low organic carbon, water current, and/or fish predation.

Only Edwards (1975) reported highest diversity in the discharge cove and attributed it to the presence of both riverine and lake insects. The high diversity that Edwards found might have been due to differences in sampling location or depth. Like other investigators, she also found low numbers of aquatic insects at the discharge cove throughout the study and believed that water current and unsuitable substrate were the causative factors. All investigators have concluded that substrate type was more important in limiting insect populations than water temperature.

METHODS AND MATERIALS

COLLECTION FREQUENCY AND LOCATION

Samples were collected at six locations in Lake Keowee and two locations in Lake Hartwell (Chapter 1, Figure 1-1 and 1-8) in February, May, August, and November, 1973 through 1976. Collections were made at each location in the littoral zone, and in either the sublittoral or profundal zones. In May 1974, sampling locations 501.0, 504.0, and 505.0 were moved from the profundal zone to the sublittoral zone because very few macroinvertebrates were collected from the profundal zone (Table 7-1).

FIELD AND LABORATORY PROCEDURES

Samples were collected with a modified Petersen grab which samples approximately 258 cm^2 (40 in^2) of substrate. Three replicate grabs were collected at each location, except for 10 grabs at Location 508.0(B). Sediment temperature was recorded from the first grab. Location,sampling depth, and sediment temperature are listed in Table 7-1.

The littoral zone at each location was sampled for two minutes with a circular sweep net (800μ mesh) as described by Paterson and Fernando (1969). Enumeration of benthic organisms in sweep net samples was discontinued in 1976, but representative macroinvertebrates were identified and included on a qualitative checklist. Core sampling was initiated in February 1976, to supplement qualitative littoral data. This procedure consisted of pressing a cylindrical core sampler, 5.1 cm diameter, into the substrate to a depth of approximately 5 cm. Three replicate samples were taken at each location. In May, 1976 and sampling periods thereafter, a larger core sampler (12.7 cm diameter) was used because of the extremely low numbers of organisms collected with the small core in February.

All benthic samples were washed in the field using a specially constructed washer with an approximate screen aperture of 500μ. Wildco wash buckets (∿ 500μ mesh) were substituted in May 1975 for the benthic washer apparatus. Washed samples were transferred to quart jars and preserved in 70% ethanol containing 0.25 g/l Rose Bengal stain.

In the laboratory, samples were hand-picked with the aid of a 2X magnifying lens. Macroinvertebrates were subsequently identified to the lowest practicable taxonomic level (usually genus) with appropriate microscopic techniques and taxonomic keys (Beck 1968; Brinkhurst 1971; Edmondson 1959; Mason 1973; Needham 1962; Pennak 1953; Petersen 1951; and Usinger 1963). The organisms were then preserved in 70% ethanol. Wet weight biomass (to the nearest 0.1 mg) of the major macroinvertebrate groups (chironomids, oligochaetes, chaoborids, and others) was recorded for each sample from August 1973 to November 1976.

SEDIMENT ANALYSIS

The substrate of each sampling location was qualitatively characterized in the field. In addition, grab samples were collected quarterly from August 1974 to November 1975, and analyzed for particle size (A.S.T.M., Method D422, 1972) and total organic carbon content (Oceanography International Total Carbon System). Sediments were described according to the procedures presented by Inman (1952).

RESULTS AND DISCUSSION

SEDIMENT TEMPERATURE

Sediment temperatures were not noticeably higher at the discharge locations (508.0A and B) compared to locations with similar depths (Table 7-1). Although sediment temperatures in Lake Keowee increased during the study, the maximum temperature noted (28.5 C) was not considered detrimental to the benthic communities. Curry (1965) reported that chironomids in general can survive seasonal temperature fluctuations between 0 and 32 C. In addition, Trembley (1961) observed that chironomid larvae survived in a heated effluent which reached 41.6 C during summer when no other aquatic invertebrates survived.

DISSOLVED OXYGEN

Low DO generally occurred during summer stratification in deep water (>20 m) (Chapter 3). Although many chironomids can survive low DO, it is doubtful that they would select a habitat with DO levels under 1 mg/l (Curry 1965). Oligochaetes (particularly Tubificidae) can withstand extended periods of oxygen depletion (Brinkhurst and Cook 1974) and would be expected to flourish in profundal areas with low DO and decreased interspecific competition.

SEDIMENT ANALYSIS

Mean particle size (MPS) of Lake Keowee sediments (Table 7-2, Fig. 7-1) was in the silt category (4.0 to 8.0 phi units) except for Location 508.0A, which is exposed to the washing action of the ONS discharge. MPS (phi units) was correlated with organic carbon content ($r = 0.50$, $p<0.05$) and depth ($r = 0.53$, $p<0.05$). Deeper locations had finer substrates with more organic material than shallow locations exposed to wave action.

Lake Keowee sediments were poorly sorted, as indicated by the phi dispersion value, which is an approximation of the standard deviation of the sediment particle size distribution and a measure of sediment sorting. The greater the phi dispersion value, the poorer the sorting, since the range of sediment particle sizes is larger (Seibel et al. 1974). Skewness is a measure of the tailing of a distribution as indicated by the difference between the mean and the median. Positive skewness values, such as those yielded by the Lake Keowee sediments, indicated that the distributions tailed toward the finer particle sizes. Mean organic carbon content (Table 7-3) was less than two percent.

The substrate at Lake Hartwell locations was predominantly poorly sorted silt with low organic carbon content. No correlation existed in Lake Hartwell between MPS and depth ($r = 0.38$, $p>0.05$) or between MPS and organic carbon content ($r = 0.15$, $p>0.05$) as it did in Lake Keowee.

LAKE HARTWELL

Sweep Net and Core Samples

A total of 98 taxa were identified in littoral samples; chironomids (44 taxa) and oligochaetes (17 taxa) were the most diverse groups (Table 7-4). Total number of taxa collected at Locations 604.0 (73) and 606.0 (82) were similar.

Chironomids, oligochaetes, and ceratopogonids were the most abundant macroinvertebrates, accounting for over 71% of the total number of organisms collected at each location. Densities were highest at Location 606.0 from 1973 through 1975 but were slightly higher at Location 604.0 in 1976 (Figs. 7-2 and 7-3).

Chironomids were the dominant macroinvertebrates in the Lake Hartwell littoral zone. Most chironomid taxa were members of the subfamily Chironominae with 21 taxa collected at each location. Seven and ten genera of Tanypodinae were collected at Locations 604.0 and 606.0, respectively. Although some species of Chironomidae are predaceous, most of them are herbivorous, feeding on diatoms, green algae, tissue of aquatic plants, and plankton, or detrivorous, feeding on decaying organic matter. Most members of the subfamily Chironominae dwell in sluggishly flowing or quiet waters. The Tanypodinae are free-living and predaceous, feeding largely upon other Chironomidae. The taxonomic composition of the chironomid fauna did not change appreciably through time, although numbers of chironomids collected did vary.

Palpomyia complex (Ceratopogonidae), were the primary biting midges collected from the Lake Hartwell littoral zone. Palpomyia larvae were more numerous at Location 606.0 than at Location 604.0. Low numbers of _Palpomyia_ larvae were noted in February, which could indicate either a winter emergence period, or the presence of early instars which may have passed through the 800μ mesh sweep net.

Although the class Oligochaeta was considered quantitatively as a single group in this study, a qualitative species checklist was compiled from oligochaetes collected in 1975. The oligochaete fauna was similar at each location, with 14 taxa at Location 604.0 and 15 taxa at Location 606.0; oligochaetes were more numerous at Location 606.0 (Table 7-4). Oligochaetes comprised approximately 35% of the macroinvertebrates collected. The Naididae and Tubificidae were the most abundant and diverse families (Table 7-4). Naids commonly found at both locations were *Nais variabilis* and *Stylaria lacustris*. These species prefer habitats with an abundant food supply such as algae and plant fragments. Although tubificids were limited in the littoral samples of Lake Hartwell by food and habitat preference, *Aulodrilus piqueti* was collected frequently. Tubificids commonly occur in soft sediments, tolerate low DO, and feed on bacteria. The only other oligochaetes found were two species of Lumbriculidae which occurred sporadically and comprised a minor part of the oligochaete fauna.

LAKE HARTWELL

Grab Samples

Sixty-nine taxa of macroinvertebrates were identified in grab samples from Lake Hartwell (Table 7-4). Chironomids (37 taxa) and oligochaetes (17 taxa) were the most diverse groups. More invertebrate taxa were found at Location 606.0 (64) than at Location 604.0 (42). The diverse benthic community at Location 606.0 was associated with benthic algae. The benthos was dominated at both stations by chironomids, oligochaetes, chaoborids, and ceratopogonids, which accounted for more than 92% of the organisms collected. Seasonal changes in diversity (number of taxa) were inconsistent (Fig. 7-4).

Macroinvertebrate density was higher at Location 606.0 than at 604.0 (Fig. 7-5). Density of benthos displayed no discernible pattern by season but was highest at both locations in 1974.

Peak biomass (standing crop) of benthos was observed in February 1976 at Location 604.0 (83,020 mg/m^2) and in May 1976 at Location 606.0 (2650 mg/m^2) (Fig. 7-6). The peaks were a result of *Corbicula manilensis* at Location 604.0 and *Hexagenia* spp. at Location 606.0. Chironomids, oligochaetes, and chaoborids accounted for 92.7% (1974), 64.2% (1975), and 2.5% (1976) of the standing crop. The decrease in percentage of standing crop of the above mentioned groups resulted from the invasion of *C. manilensis*.

Chironomid diversity was comparable at both locations, with 32 taxa at Location 606.0 and 29 taxa at Location 604.0. Chironomids collected from grab samples were as diverse as those from sweep net and core samples. The subfamily Chironominae was the most diverse chironomid group with 17 taxa at Location 604.0 and 16 taxa at Location 606.0. The Tanypodinae had the second greatest variety at Location 606.0 (12 taxa) and 604.0 (7 taxa). The high diversity and abundance of chironomids at Lake Hartwell was expected since the fine sediments (Table 7-2) with relatively high organic carbon content (Table 7-3) represent optimal habitat for certain chironomids (Wene 1940; Topping 1971; McLachlan and McLachlan 1971).

Peak density of chironomids was noted in February 1975, with 582/m^2 at Location 604.0 and 3864/m^2 at Location 606.0 (Fig. 7-7).

Peak standing crop of chironomids occurred in the same period as peak density (February 1975). Seasonal variations in standing crop were similar to those of density. In general, chironomid standing crop was highest at Location 604.0.

The larvae of Chaoborus punctipennis (phantom midges) were important members of the Lake Hartwell benthic community and accounted for 17.8% of the total number. Phantom midge larvae were more numerous at Location 604.0 than at 606.0 (Fig. 7-7). The high numbers of C. punctipennis, a benthic predator, at Location 604.0 may be related to the abundance of chironomids (prey organisms) or to increased depth. Seasonal dynamics of C. punctipennis larvae were difficult to elucidate. Peak densities occurred in summer and fall with the highest density of C. punctipennis in November 1976 at Location 604.0 ($724/m^2$). Numbers of phantom midges declined noticeably from 1973 through 1975 and peaked again in August and November 1976. Factors responsible for this variability in populations were not apparent. The standing crop of Chaoborus punctipennis was higher at Location 604.0 than at 606.0 with peak standing crop in November 1976 ($572 mg/m^2$).

Ceratopogonid larvae (Palpomyia complex) accounted for 5.4% of macroinvertebrate density for the four year period. There was a general increase in ceratopogonids from 1973 through 1975 at both locations with consistently higher densities of Palpomyia larvae occurring at Location 606.0 than at 604.0 (Fig. 7-8). Again, these differences in densities may be related to depth differences.

The oligochaete fauna was fairly diverse, with 5 taxa at Location 604.0 and 19 at Location 606.0. Naididae (10 taxa) and Tubificidae (7 taxa) were the dominant families, with Nais variabilis and Stylaria lacustris the primary naids and Ilyodrilus templetoni and Limnodrilus spp. the most abundant tubificids.

Oligochaetes accounted for approximately 29% of the benthos density. Oligochaetes were more abundant at Location 606.0 than 604.0. Peak densities of oligochaetes consistently occurred in May and August (Fig. 7-8). Abundance of oligochaetes in August was possibly related to decreased predation due to the emergence of chaoborids and chironomids. Lellack (1975) found that there may be intense competition between certain detritophagus chironomids and oligochaetes. Peak standing crop of oligochaetes was recorded in 1974. Seasonal variation in oligochaete standing crop indicated peaks in February and May.

LAKE KEOWEE

Sweep Net and Core

Chironomids, ceratopogonids, and oligochaetes were dominant in the littoral zone, comprising 60%, 12%, and 8%, respectively. Ninety-five macroinvertebrate taxa were collected, with chironomids (41 taxa) and oligochaetes (11 taxa) being the most diverse groups (Table 7-5). The most diverse benthic community occurred at Location 505.0 with 59 taxa. Lowest diversity was observed at Location 502.0 (35 taxa) which is near the skimmer wall. This low diversity is typical of the hard packed clay substrate, which is a poor habitat for macroinvertebrates.

High diversity of chironomids was found at Location 504.0 and 506.0, whereas low diversity was recorded from Location 501.0 and 502.0. In the discharge cove, chironomid diversity was intermediate. The Chironominae (27 taxa) was the most abundant subfamily in shoreline samples with Orthocladiinae (7 taxa) and Tanypodinae (6 taxa) of lesser importance. The major Orthocladiinae included Parakiefferiella sp. and Psectrocladius sp. while Potthasia longimanus was the only Diamesinae collected (Location 508.0).

ed in 1975. The oligochaete fauna was similar at each location, with at Location 604.0 and 15 taxa at Location 606.0; oligochaetes were merous at Location 606.0 (Table 7-4). Oligochaetes comprised approximately the macroinvertebrates collected. The Naididae and Tubificidae were t abundant and diverse families (Table 7-4). Naids commonly found at cations were Nais variabilis and Stylaria lacustris. These species habitats with an abundant food supply such as algae and plant fragments. h tubificids were limited in the littoral samples of Lake Hartwell by d habitat preference, Aulodrilus piqueti was collected frequently. ids commonly occur in soft sediments, tolerate low DO, and feed on bacteria. y other oligochaetes found were two species of Lumbriculidae which d sporadically and comprised a minor part of the oligochaete fauna.

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The benthic community was dominated numerically by chironomids, oligochaetes, and chaoborids, collectively accounting for approximately 91% of the benthos. Macroinvertebrates were most abundant at Locations 501.0 and 506.0 due to the fine silt substrate (Table 7-2) and relatively high organic carbon (Table 7-3), which supports high density benthic populations. In contrast, the discharge substrate, with lowest invertebrate density, had larger particles and low organic content. Macroinvertebrate density generally peaked in November and February with maximum density at Location 501.0 in February 1975.

Peak density of chironomids generally occurred in February and May, prior to the primary emergence period in summer (Fig. 7-14). Based on pupal collections, chironomids emerged in all sample periods except winter (February). There was a general increase in chironomids from 1973 through 1976. This increase may have been related to the decline of Chaoborus punctipennis, a benthic predator, and/or may also be related to the change in sampling Locations 501.0, 504.0, and 505.0, from the profundal zone to the sublittoral zone, where chironomids are typically more abundant.

Seasonal variations in densities of Chaoborus punctipennis were difficult to discern. Peak density occurred in November, 1973 at the discharge cove (Location 508.0B) with a decline in February, May, and August, 1974. Densities of C. punctipennis declined in both lakes from 1973 through August, 1976 and increased again in November 1976 (Fig. 7-15). The cause of this abrupt decline is not known, although natural population fluctuations or successional changes in the lake could possibly have been the cause. Numbers of C. punctipennis larvae returned to pre-decline levels by November, 1976.

Oligochaetes were most abundant at Location 506.0, which had fine sediments and relatively high organic carbon (Tables 7-2 and 7-3). Oligochaete density was comparatively low in the discharge, which had a coarse substrate with low organic carbon. Most peaks in oligochaete density occurred in fall and winter. Abundance of oligochaetes increased from 1973 to 1976 (Fig. 7-16).

Maximum standing crop (mg/m^2) generally occurred in February and November with the peak at Location 506.0 in February, 1974 and the low at Location 508.0(A) in August, 1975 (Fig. 7-13). High standing crop was related to small particle size and high organic carbon content of the sediments. Chironomid and oligochaete standing crops were highest in 1975; no seasonal patterns of standing crop were observed. Variations in standing crop of Chaoborus punctipennis were erratic, but relative peaks were consistently observed in November at the discharge cove (Location 508.0B).

In addition to the above, similar results were reported in a special study by the Southeast Reservoir Investigations (SERI), U. S. Fish and Wildlife Service, on the Benthos of Keowee Reservoir (Addendum A-6).

SUMMARY AND CONCLUSIONS

LAKE HARTWELL

Based on our studies, the benthos of Lake Hartwell was not affected by the operation of ONS. The benthic community of Lake Hartwell, dominated numerically by chironomids, oligochaetes, chaoborids, and ceratopogonids, was very diverse and abundant. Macroinvertebrate diversity was similar at both littoral locations sampled, although abundance was considerably greater at Location 606.0. Highest diversity and abundance in the littoral zone occurred in August and November.

Grab samples revealed a more diverse and abundant benthic fauna at Location 606.0 than at Location 604.0. Peak diversity and abundance of macroinvertebrates from grab samples were recorded in February 1975 and May 1974, respectively. Standing crop was greatest in winter and spring.

LAKE KEOWEE

Although the benthos collected in Lake Keowee littoral samples was fairly diverse, it could not be considered abundant. The benthic community was dominated by chironomids, oligochaetes, and ceratopogonids. Diversity was highest in Location 504.0 and 505.0 and was similar in the discharge cove. Abundance was high at Locations 504.0, 505.0, and 506.0. Low abundance of benthos in the discharge cove was attributed to unsuitable substrate and to the adverse effects of wave action.

Chironomids, oligochaetes, and chaoborids dominated the sublittoral and profundal benthos in Lake Keowee. Chironomids and oligochaetes were the most diverse groups. Highest diversity was recorded at Location 501.0 with moderately high diversity in the discharge cove. Benthos was most abundant at Location 501.0 and 506.0, and least abundant in the discharge cove. Low diversity and density in the discharge cove were related to the unsuitable substrate. The benthic community was most diverse in fall and winter.

The most important change in the benthic fauna of Lake Keowee, from 1973 through August, 1976, was the decline in *Chaoborus punctipennis*. This phenomenon may be related to natural fluctuations in populations or other indiscernible causes. Densities of *C. punctipennis* returned to pre-decline levels in November 1976.

Important findings by SERI included:

1. reduced density and diversity of chironomid larvae in the discharge,
2. increased oligochate populations in the discharge,
3. earlier spring emergence patterns of chironomids within the plume, and
4. decline in planktonic *Chaoborus* populations with increased operational level of Oconee Nuclear Station.

RECOMMENDATIONS

Quarterly sampling of benthic communities in Lakes Keowee and Hartwell has consistently shown the discharge to have low densities, diversity, and standing crop in comparison with other stations. However, as this study and others (Langston 1973; Edwards 1975; Forsyth 1975; Hudson 1975; Fyals 1975; and Sigmon et al. 1975) have shown, this decrease was due to unsuitable substrate, fish predation, wave action, and/or low organic carbon, rather than increased thermal and associated water quality changes. None of the aforementioned studies have found effects directly related to the operation of ONS, and based on our findings, it is believed that ONS has not adversely affected the benthos of Lakes Keowee and/or Hartwell. Therefore, is is recommended that the monitoring requirements of Technical Specification 1.3.5 Benthos be eliminated.

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Table 7-1

Depth (m)[1], and bottom temperature (C)[2], of benthic sampling locations in the sublittoral and profundal zones in Lakes Keowee and Hartwell, 1973-1976.

Location	Jan 1973	May 1973	Jul 1973	Nov 1973	Feb 1974	May 1974	Aug 1974	Nov 1974	Feb 1975	May 1975	Aug 1975	Nov 1975	Feb 1976	May 1976	Aug 1976	Nov 1976
L. Keowee																
501.0	20[1] 9.0[2]	16 10.6	15 15.0	15 19.5	14 12.0	8 20.0	8 25.0	9 21.5	8 10.5	8 19.0	8 28.0	8 22.0	7 9.5	8 19.0	9 25.0	8 18.0
502.0	15 9.0	27 9.0	27 11.0	27 12.3	26 11.5	24 13.5	26 16.0	27 19.5	27 10.0	28 14.0	28 18.0	28 21.0	23 9.5	29 14.5	27 16.5	27 18.0
504.0	33 8.5	19 9.5	23 11.5	23 11.0	18 12.0	7 17.0	9 26.5	9 21.0	7 12.0	9 19.0	9 28.0	8 23.0	8 12.5	7 19.5	8 25.5	8 20.0
505.0	26 8.0	33 8.3	34 10.0	31 10.5	33 10.5	8 19.0	8 27.5	9 21.5	8 13.0	9 19.0	8 28.0	9 22.0	8 12.5	8 17.0	9 25.5	8 20.0
506.0	29 8.0	32 8.3	33 10.0	33 11.0	31 10.8	32 12.5	31 15.0	37 14.0	31 11.0	38 14.0	33 14.0	30 20.0	28 10.6	34 12.5	34 19.0	30 10.5
508.0A	*	*	*	*	*	8 19.0	9 25.5	9 21.5	8 12.0	8 19.5	7 28.5	8 23.0	*	*	*	*
508.0B	12 8.5	19 9.5	16 16.0	19 18.0	22 11.5	19 15.8	19 22.0	21 19.5	18 12.0	19 20.0	20 24.5	22 21.0	18 12.5	20 16.0	20 21.5	20 19.0
L. Hartwell																
604.0	6 8.5	5 18.4	5 27.0	5 17.8	5 12.5	5 20.0	5 27.0	4 20.0	5 12.0	5 20.0	5 27.5	4 21.0	5 13.5	5 19.0	4 28.0	5 20.0
606.0	3 8.5	3 18.4	3 24.5	3 18.0	3 10.5	3 19.0	3 25.0	3 19.0	3 12.0	3 20.0	3 27.0	3 19.0	3 12.8	3 19.0	3 27.0	3 20.0

* Station not sampled

Table 7-2. Descriptive measures of sediments in Lakes Keowee and Hartwell, 1974-1975.

Location	Aug 74	Nov 74	Feb 75	May 75	Aug 75	Nov 75	Mean and Range
Lake Keowee							
501.0	3.6[1]	6.8	4.6	5.3	5.8	2.6	4.8 (2.6-6.8)
	3.2[2]	2.0	3.7	2.3	2.6	2.4	2.7 (2.0-3.7)
	0.56[3]	0.10	-0.11	-0.35	-0.23	0.38	0.06 (-0.35-0.56)
502.0	6.3	5.5	4.1	5.6	5.6	6.1	5.5 (4.1-6.3)
	2.6	2.2	3.6	2.0	2.6	2.6	2.6 (2.0-3.6)
	0.19	0.0	0.44	-0.20	0.0	0.15	0.10 (-0.20-0.44)
504.0	6.7	5.1	4.1	5.2	5.3	2.5	4.8 (2.5-6.7)
	3.5	2.4	3.3	2.4	4.8	2.2	3.1 (2.2-4.8)
	-0.14	0.33	-0.18	-0.21	0.63	0.32	0.13 (-0.21-0.63)
505.0	3.1	4.2	3.0	3.9	2.2	4.1	3.4 (2.2-4.2)
	2.8	3.5	2.5	2.9	1.6	3.1	2.7 (1.6-3.5)
	-0.04	0.34	0.28	0.31	0.25	0.42	0.26 (-0.04-0.42)
506.0	3.3	7.0	7.3	7.9	7.9	3.9	6.2 (3.3-7.9)
	3.0	2.6	2.0	3.0	3.1	1.8	2.6 (1.8-3.1)
	0.43	-0.08	-0.20	0.07	0.42	0.39	0.17 (-0.20-0.43)
508.0A	3.6	2.4	4.0	4.3	4.2	2.1	3.4 (2.1-4.3)
	3.3	2.7	3.8	4.0	3.7	2.4	3.3 (2.4-4.0)
	0.09	0.07	0.29	0.33	0.35	0.29	0.24 (0.07-0.35)
508.0B	6.7	5.5	3.5	4.2	4.7	4.2	4.8 (3.5-6.7)
	2.7	3.5	2.7	4.4	2.9	2.7	3.2 (2.7-4.4)
	0.26	-0.09	0.30	0.48	0.52	-0.15	0.22 (-0.15-0.52)
Lake Hartwell							
604.0	7.9	8.1	7.2	6.9	7.7	7.4	7.5 (6.9-8.1)
	2.2	2.4	2.0	2.3	2.8	2.6	2.4 (2.0-2.8)
	0.18	0.33	-0.20	-0.17	0.50	0.31	0.16 (-0.20-0.50)
606.0	5.6	4.3	5.2	6.7	5.9	6.3	5.7 (4.3-6.7)
	2.2	1.8	1.9	3.7	2.8	2.8	2.5 (1.8-3.7)
	0.18	0.11	0.21	0.24	0.07	0.32	0.19 (0.07-0.32)

[1] Mean particle size
[2] Phi dispersion value
[3] Skewness

Table 7-3. Percentages of silt, clay, and organic carbon in sediments of Lakes Keowee and Hartwell, 1974-1975.

Location	Aug 74	Nov 74	Feb 75	May 75	Aug 75	Nov 75	Mean and Range
Lake Keowee							
501.0	28[1]	89	60	76	74	21	58 (21-89)
	0.2[2]	0.63	1.27	1.40	1.55	*	1.01 (0.2-1.6)
502.0	82	73	35	79	68	77	69 (35-82)
	0.85	0.31	0.43	0.45	0.69	*	0.55 (0.31-0.85)
504	72	52	53	71	31	20	50 (20-72)
	4.43	0.50	0.48	1.28	0.77	*	1.49 (0.48-4.43)
505.0	34	32	20	38	16	36	29 (16-28)
	0.29	0.54	0.51	1.03	0.69	*	0.61 (0.29-1.03)
506.0	33	86	90	96	93	32	72 (32-96)
	0.56	0.59	1.53	1.07	4.75	*	1.70 (0.56-4.75)
508.0A	33	22	39	38	38	55	38 (22-55)
	0.28	0.25	0.51	0.36	2.02	*	0.69 (0.25-2.02)
508.0B	84	66	29	30	33	18	43 (18-84)
	0.39	0.35	0.27	0.90	0.88	*	0.56 (0.27-0.90)
Lake Hartwell							
604.0	98	96	88	87	94	93	93 (87-98)
	0.61	0.64	1.04	1.34	2.77	*	1.28 (0.61-2.77)
606.0	68	50	64	67	73	73	66 (50-73)
	0.38	0.29	*	*	4.76	*	1.81 (0.29-4.76)

[1] % silt, clay
[2] % organic carbon
* % organic carbon not determined

Table 7-4

Checklist of Benthic Macroinvertebrate Taxa from Lake Hartwell from 1973 to 1976.

	SWEEP NET & CORE		GRAB	
	Location		Location	
Organism	604.0	606.0	604.0	606.0
Diptera				
Chironomidae				
Chironomidae (pupae)	+	+	+	+
Tanypodinae				
Ablabesmyia spp.	+	+		+
A. americana	+			+
A. aspera		+		
A. janta	+	+		+
A. mallochi		+		+
A. ornata	+	+		+
Coelotanypus spp.		+	+	+
C. concinnus			+	+
C. scapularis			+	+
C. tricolor	+		+	
Procladius spp.	+	+	+	+
P. (*Psilotanypus*) *bellus*	+	+	+	+
P. (*Procladius*) spp.		+	+	+
Tanypus spp.		+		
Orthocladiinae			+	
Cricotopus sp.	+	+	+	+
Nanocladius sp.	+			
Orthocladius spp.		+		
Parakieferiella sp.	+	+	+	+
Psectrocladius sp.	+	+	+	+
Smittia spp.	+	+		
Chironominae				
Chironomini				
Chironomus sp.	+	+	+	+
Cryptochironomus sp.	+	+	+	+
Cryptocladopelma sp.	+	+	+	
Cryptotendipes sp.	+	+		+
Dicrotendipes sp.	+	+	+	+
Endochironomus sp.		+		
Glyptotendipes sp.	+	+	+	+
Harnischia sp.		+	+	+
Microtendipes sp.	+		+	
Nilothauma sp.	+			
Pagastiella sp.	+	+	+	+
Parachironomus sp.	+	+		
Paracladopelma sp.				+
Paralauterborniella sp.			+	
Phaenopsectra (*Tribelos*) spp.	+			
Polypedilum spp.	+	+	+	+
P. (*Nubeculosum*) grp.	+			
P. (*Tripodura*) grp.	+	+	+	+

Table 7-4 (Cont.)

Organism	SWEEP NET & CORE Location 604.0	SWEEP NET & CORE Location 606.0	GRAB Location 604.0	GRAB Location 606.0
Pseudochironomus sp.	+	+	+	+
Stenochironomus sp.		+		
Stictochironomus sp.	+	+	+	+
Tanytarsini				
Cladotanytarsus sp.	+	+	+	+
Micropsectra sp.	+	+	+	+
Rheotanytarsus sp.	+	+	+	+
Stempellina sp.	+	+		
Tanytarsus sp.	+	+	+	+
Zavrelia sp.		+		
Diamesinae				
Potthastia longimanus		+		
Ceratopogonidae	+			
Alluaudomyia spp.	+	+		
Palpomyia complex (*Palpomyia* sp., *Bezzia* sp., *Probezzia* sp., *Johannsenomyia* sp.)	+	+	+	+
Chaoboridae				
Chaoborus punctipennis	+	+	+	+
C. punctipennis (pupae)	+	+		+
Dolichopodidae	+	+		
Phoridae		+		
Tabanidae	+	+		
Tipulidae		+		
Trichoptera				
Hydroptilidae	+			+
Agraylea sp.		+		
Oxyethira sp.	+	+		
Leptoceridae		+		
Oecetis sp.	+	+	+	+
Polycentropodidae		+		+
Phylocentropus sp.				+
Polycentropus sp.	+	+		+
Ephemeroptera		+		
Caenidae		+		
Caenis sp.	+			
Ephemerellidae		+		
Ephemerella sp.				
Ephemeridae				
Hexagenia spp.	+		+	+
Coleoptera				
Hydrophilidae				
Berosus sp.		+		
Hemiptera				
Veliidae				
Microvelia sp.	+			
Odonata	+			
Anisoptera				
Gomphidae	+			
Dromogomphus sp.	+	+		
Gomphus sp.	+	+		+

Table 7-4 (Cont.)

Organism	SWEEP NET & CORE Location 604.0	606.0	GRAB Location 604.0	606.0
Libellulidae		+		
Macromiinae				
Didymops sp.		+		
Macromia sp.	+	+		
Libellulinae				
Stomatochlora sp.		+		
Zygoptera				
Coenagrionidae	+	+		
Megaloptera				
Sialidae				
Sialis sp.	+	+		
Acariformes				
Hydrachnellae (Hydracarina)		+		
Oligochaeta				
Naididae		+		
Aulophorus vagus	+	+		+
Dero spp.	+			
Nais spp.	+	+		+
N. communis		+		+
N. simplex				+
N. variabilis	+	+	+	+
Pristina spp.				+
P. bilobata	+			+
P. longiseta				+
Stylaria fossularis	+	+		+
S. lacustris	+	+	+	+
Lumbriculidae	+	+		+
Lumbriculus variegatus	+	+	+	+
Tubificidae	+	+		
Aulodrilus limnobius		+	+	+
A. piqueti	+	+	+	+
Ilyodrilus templetoni				+
Limnodrilus sp.	+	+		+
L. hoffmeisteri		+		+
Bothrioneurum vejdovskyenum	+	+		+
Peloscolex freyi				+
Nematoda	+	+	+	+
Nemertinea				
Prostoma spp.			+	+
Mollusca				
Gastropoda				
Physidae				
Physa sp.	+			
Pelecypoda	+		+	
Corbiculidae				
Corbicula manilensis	+		+	+

Table 7-4 (Cont.)

Organism	SWEEP NET & CORE Location 604.0	606.0	GRAB Location 604.0	606.0
Bryozoa				
Plumatellina				
Lophopodidae				
Pectinatella magnifica	+	+	+	+
Total Taxa	73	82	43	65

Table 7-5

Checklist of Benthic Macroinvertebrate Taxa from Lake Keowee from 1973 to 1976.

Organism	Location	SWEEP NET AND CORE						GRAB					
		501.0	502.0	504.0	505.0	506.0	508.0	501.0	502.0	504.0	505.0	506.0	508.0
Diptera													
Chironomidae													
Chironomidae (pupae)		+	+	+	+	+	+	+	+	+	+	+	+
Tanypodinae													
Ablabesmyia spp.		+		+	+	+	+			+	+		+
A. americana											+		
A. aspera			+	+		+							
A. janta								+		+	+		
A. mallochi		+	+		+	+	+	+			+	+	
A. ornata								+					
Coelotanypus scapularis								+	+	+			
C. concinnus								+					
Procladius spp.				+	+	+	+	+	+	+	+	+	+
P. (*Psilotanypus*) *bellus*		+	+	+		+	+	+	+	+	+	+	+
P. (*Procladius*) spp.		+		+			+	+	+	+	+	+	+
Orthocladiinae													
Cricotopus spp.			+	+	+	+	+			+	+		+
Metriocnemus sp.				+									
Nanocladius sp.				+									
Orthocladius sp.				+	+								
Parakieferiella sp.		+	+	+	+	+	+		+	+	+		+
Psectrocladius sp.		+	+	+	+	+	+	+		+	+		+
Smittia sp.		+	+	+	+	+	+						
Chironominae													
Chironomini													
Chironomus sp.		+	+	+	+	+	+	+	+	+	+	+	+
Cryptochironomus sp.		+	+	+	+	+	+	+	+	+	+	+	+
Cryptocladopelma sp.				+	+	+	+		+	+	+		
Cryptotendipes sp.					+			+		+			
Dicrotendipes sp.		+	+	+	+	+	+	+		+	+		+
Endochironomus sp.		+			+	+		+					+
Glyptotendipes sp.				+	+	+	+						
Harnischia sp.					+		+	+		+			+
Lauterborniella sp.						+			+		+		
Leptochironomus sp.				+				+		+	+		+
Microtendipes sp.								+		+			
Nilothauma sp.		+					+						
Pagastiella sp.		+	+			+		+	+	+	+	+	+
Parachironomus sp.		+			+								
Paracladopelma sp.								+	+	+	+	+	+
Phaenopsectra spp.						+							
P. (*Tribelos*) spp.					+	+							

Table 7-5 (Cont.)

		SWEEP NET AND CORE						GRAB					
Organism	Location	501.0	502.0	504.0	505.0	506.0	508.0	501.0	502.0	504.0	505.0	506.0	508.0
Polypedilum spp.		+	+	+	+	+	+	+	+	+	+		+
P. fallax						+							
P. (Nubeculosum) grp.		+	+	+	+	+	+		+				+
P. (Tripodura) grp.		+	+	+	+	+	+	+	+	+	+	+	+
Pseudochironomus sp.		+	+	+	+	+	+	+	+	+	+		+
Stenochironomus sp.			+	+		+		+			+		
Stictochironomus sp.		+	+	+	+	+	+	+	+	+	+	+	+
Tanytarsini										+			
Cladotanytarsus sp.		+	+	+	+	+	+	+		+	+		+
Micropsectra sp.		+	+	+	+	+	+	+	+	+	+		+
Rheotanytarsus sp.				+	+	+		+					+
Stempellina sp.		+	+	+	+	+	+	+		+	+		+
Tanytarsus sp.		+	+	+	+	+	+	+	+	+	+	+	+
Diamesinae													
Potthastia longimanus							+						
Ceratopogonidae													
Alluaudomyia sp.		+		+	+	+							
Atrichopogon sp.				+									
Bezzia sp.						+							
Dasyhelea sp.		+	+	+	+	+							
Forcipomyia sp.				+									
Palpomyia complex (Palpomyia sp., Bezzia sp., Probezzia sp., Johannsenomyia sp.)		+	+	+	+	+	+	+	+	+	+		+
Chaborous punctipennis		+	+	+	+	+	+	+	+	+	+	+	+
C. punctipennis (pupae)		+	+	+	+	+	+		+	+	+	+	+
Dolichopodidae		+		+	+	+		+		+	+		
Hydrophorus sp.				+									+
Athericidae													
Atherix varigata								+					
Tipulidae													
Tipula sp.			+										
Tabanidae													
Tabanus sp.			+										
Trichoptera													
Hydropsychidae													
Hydropsyche spp.									+				
Hydroptilidae													
Oxyethira sp.				+	+	+	+						
Leptoceridae													
Nectopsyche sp.		+											

Table 7-5 (Cont.)

Organism	Location	SWEEP NET AND CORE 501.0	502.0	504.0	505.0	506.0	508.0	GRAB 501.0	502.0	504.0	505.0	506.0	508.0
Oecetis sp.		+	+	+	+	+	+	+	+	+	+		+
Polycentropodidae								+					
Nyctiophylax sp.						+							
Polycentropus sp.		+	+	+	+	+	+	+	+	+	+		
Ephemeroptera				+	+		+						
Baetidae					+								
Centroptilum sp.					+								
Ephemeridae													
Hexagenia sp.		+				+				+			
Heptageniidae													
Heptagenia sp.		+			+								
Caenidae													
Caenis sp.						+							
Siphlonuridae		+		+									
Coleoptera													
Haliplidae					+								
Hemiptera													
Gerridae													
Trepobates sp.						+							
Odonata													
Anisoptera													
Gomphidae													
Dromogomphus sp.		+											
Gomphus sp.		+			+	+	+						
Libellulidae													
Macromiinae													
Macromia sp.		+											
Didymops sp.		+											
Zygoptera													
Coenagrionidae		+		+	+		+						
Argia sp.					+	+							
Megaloptera													
Sialidae													
Sialis sp.		+			+								
Perlodidae		+											
Acariformes													
Hydrachnellae (Hydracarina)		+	+	+	+	+	+	+			+		+
Hirudinea		+					+						
Oligochaeta													
Naididae													

Table 7-5 (Cont.)

		SWEEP NET AND CORE						GRAB					
Organism	Location	501.0	502.0	504.0	505.0	506.0	508.0	501.0	502.0	504.0	505.0	506.0	508.0
Nais sp.							+						
N. variabilis		+		+	+		+	+			+	+	
N. communis		+			+		+						
Aulophorus borelli													+
A. vagus												+	+
Dero digitata								+					
Pristina sp.					+							+	
Stylaria lacustris					+		+					+	
Stylaria fossularis				+	+		+						
Lumbriculidae								+					
Lumbriculus variegatus		+					+						
Tubificidae		+	+	+	+	+	+						
Aulodrilus limnobius							+		+			+	+
Tubifex tubifex												+	
Bothrioneurum vejdovskyanum		+			+			+					
Ilyodrilius templetoni				+					+			+	
Limnodrilus spp.		+	+	+	+	+	+	+	+	+	+	+	+
Limnodrilus hoffmeisteri				+					+	+		+	
Peloscolex sp.		+											
P. freyi									+			+	
Nematoda		+	+	+	+	+	+	+	+		+	+	
Nemertinea													
Prostoma spp.		+	+	+	+	+	+						
Mollusca													
Gastropoda													
Physidae													
Physa sp.													+
Planorbidae													
Gyraulus sp.					+	+							
Total Taxa		54	35	54	59	54	49	44	31	38	38	25	37

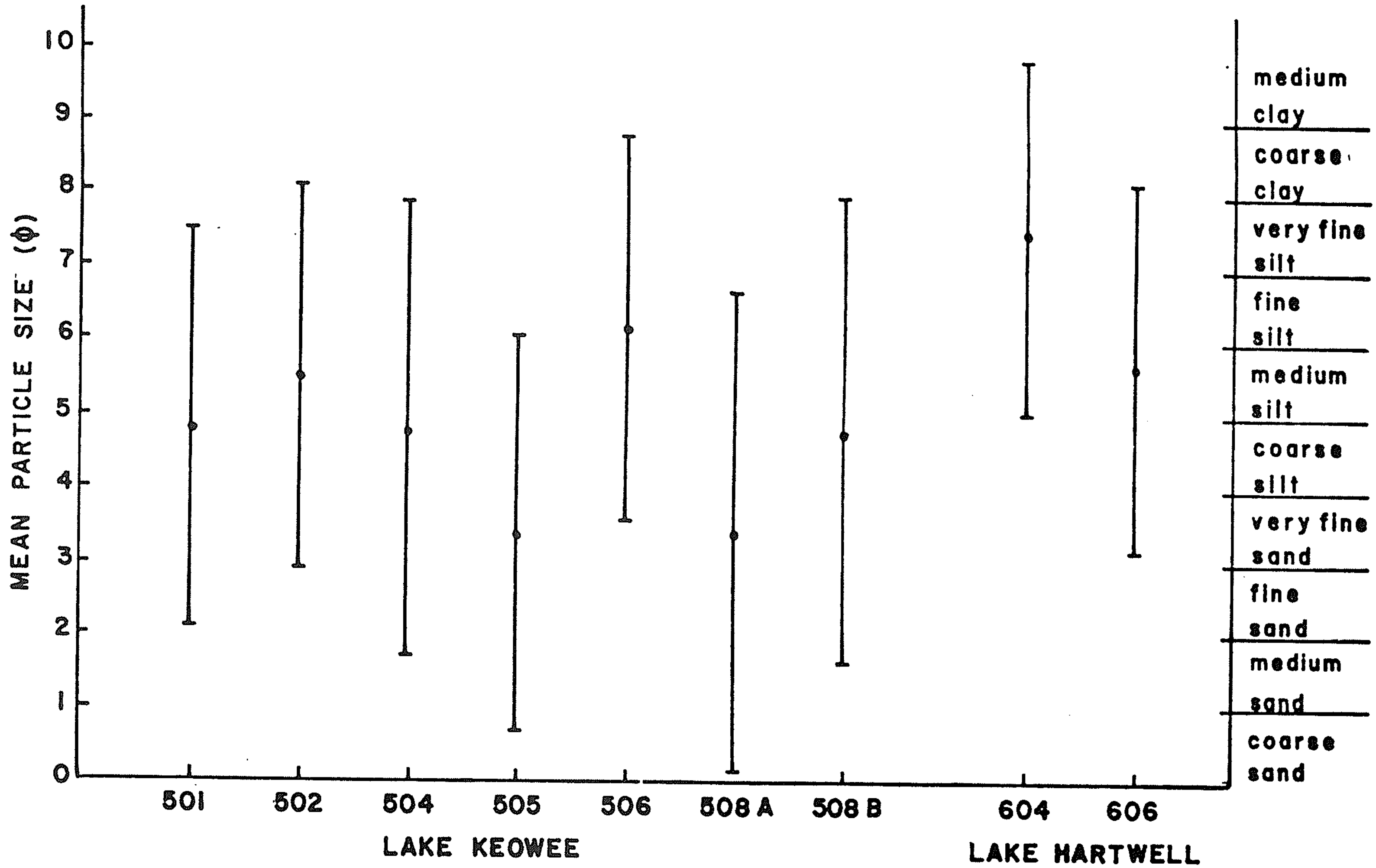


Figure 7-1. Mean particle size of sediments in Lakes Keowee and Hartwell with bars representing phi dispersion value, 1974-1975.

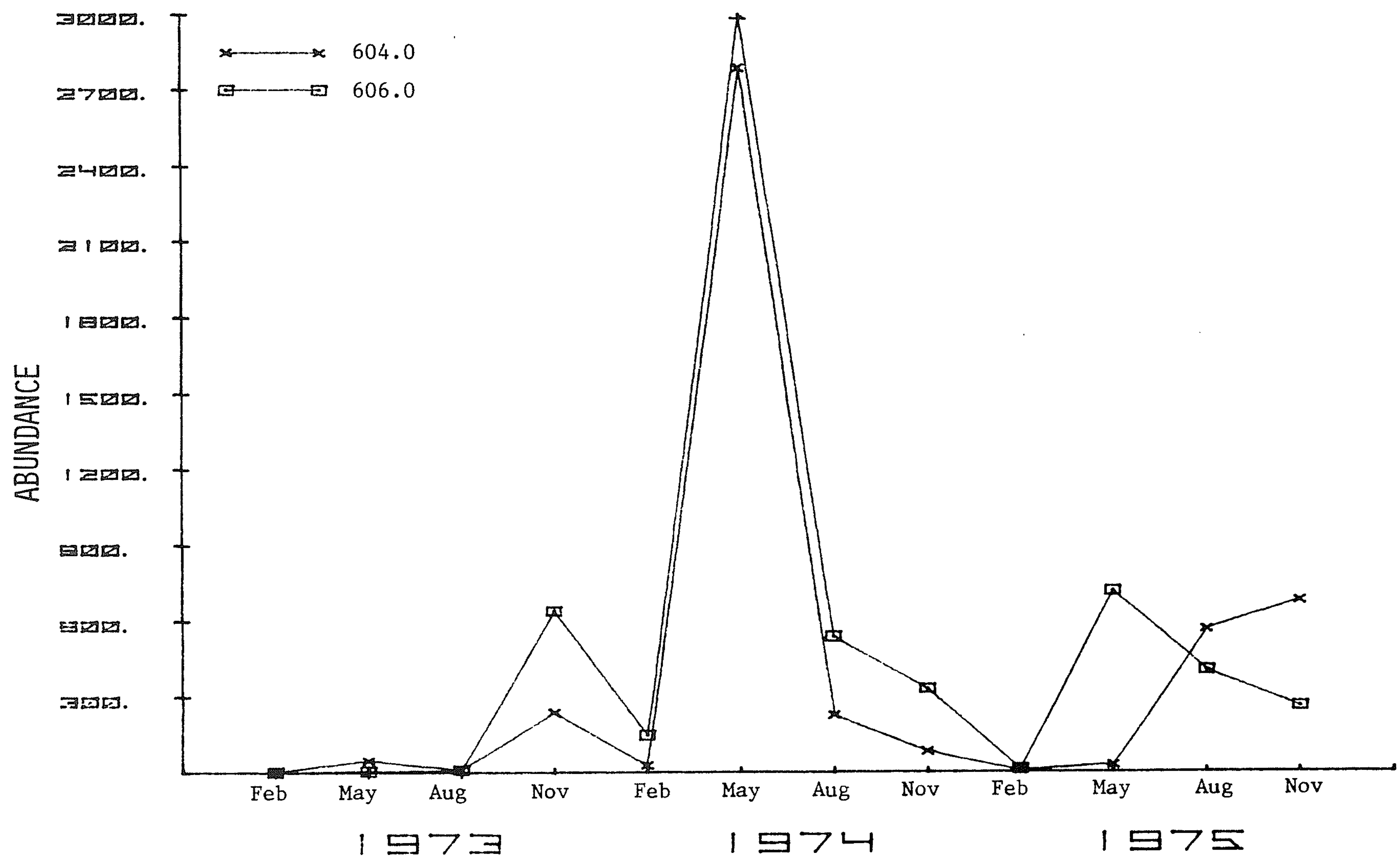


Figure 7-2. Abundance (number per two-minute sweep) of benthic macroinvertebrates at Locations 604.0 and 606.0 in Lake Hartwell from February, 1973, to November, 1975.

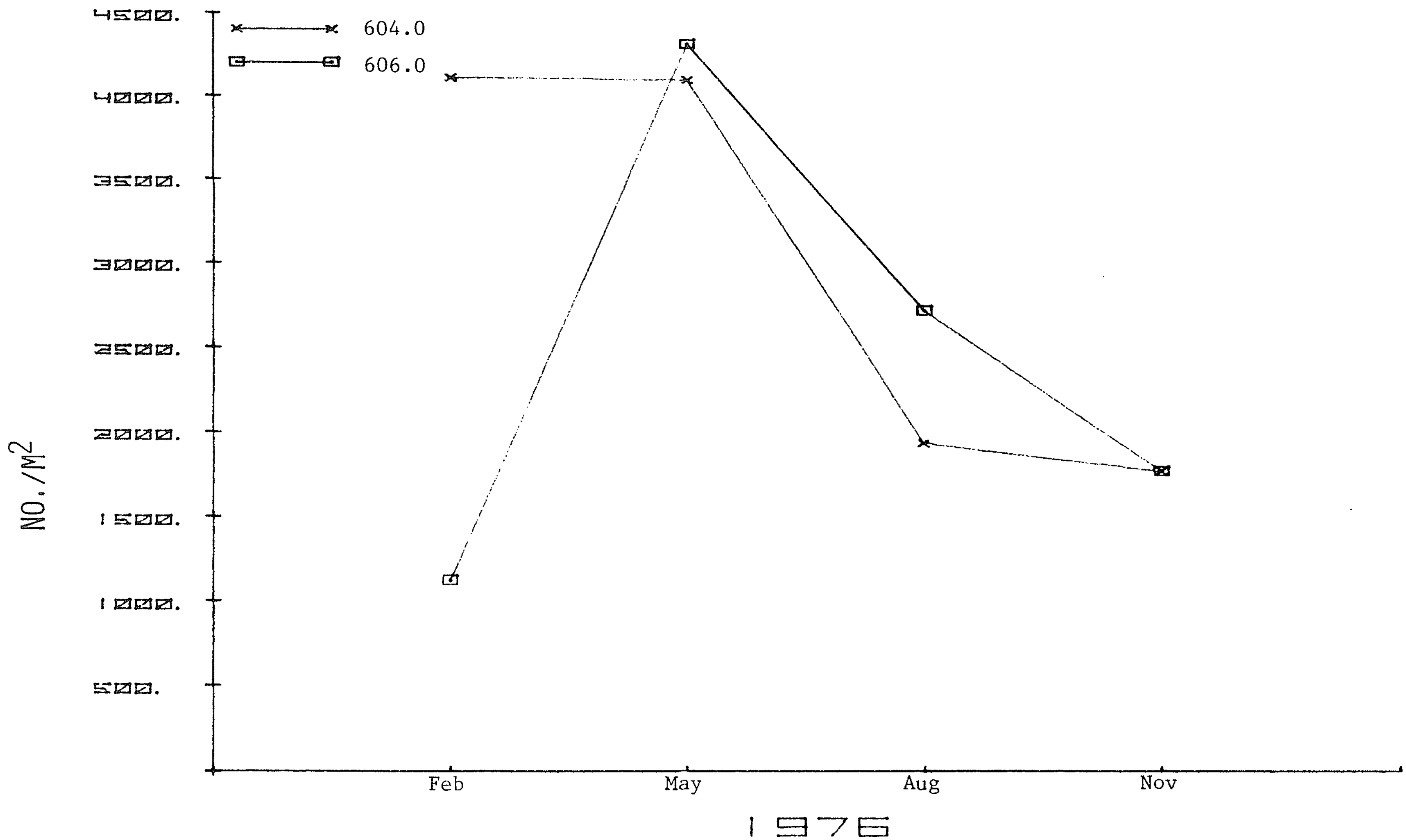


Figure 7-3. Mean density (no./m^2) of benthic macroinvertebrates collected in core samples in Lake Hartwell in 1976.

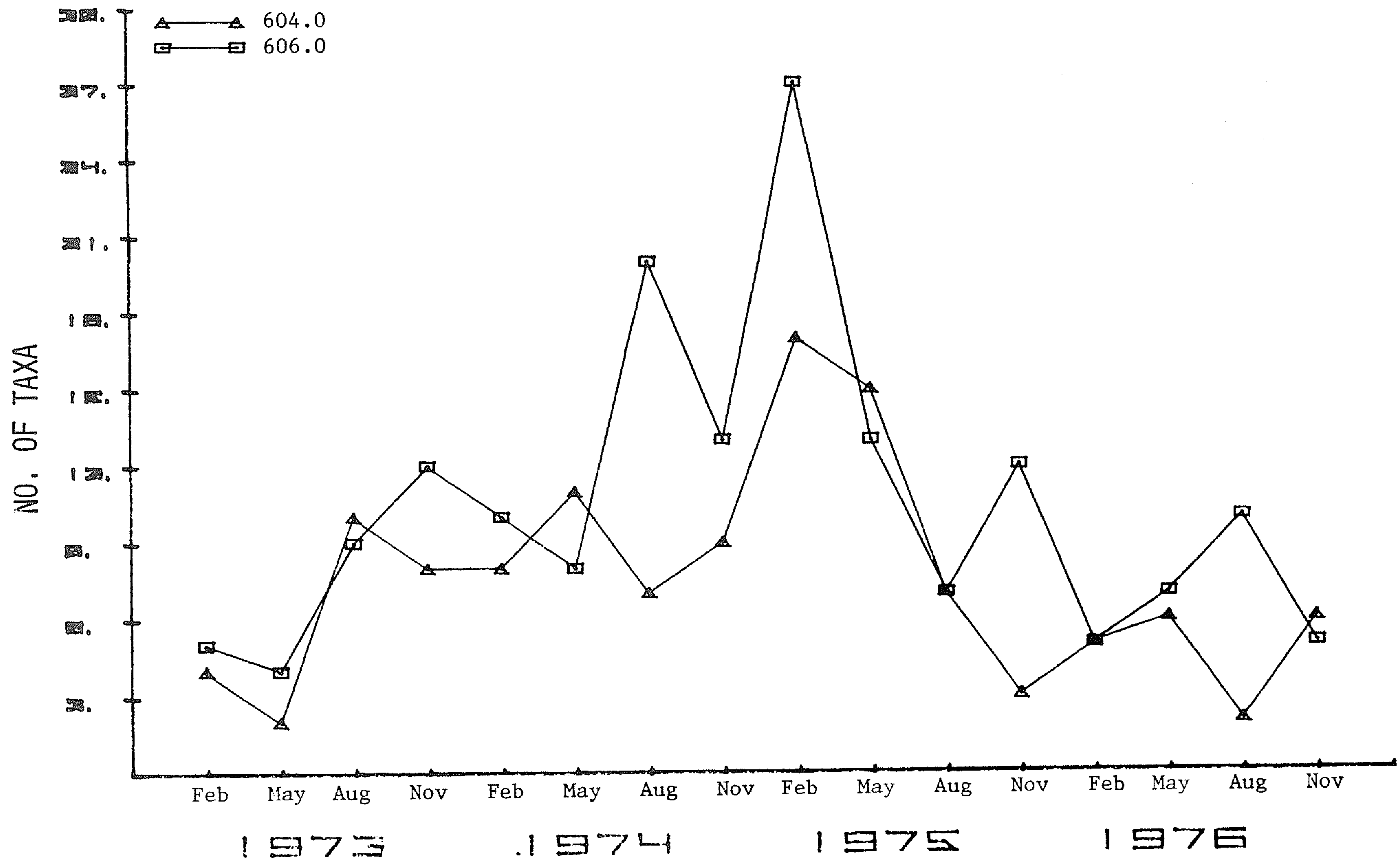


Figure 7-4. Relative diversity (number of taxa) of benthic macroinvertebrates at Locations 604.0 and 606.0 collected in grab samples from Lake Hartwell from February, 1973, to November, 1976.

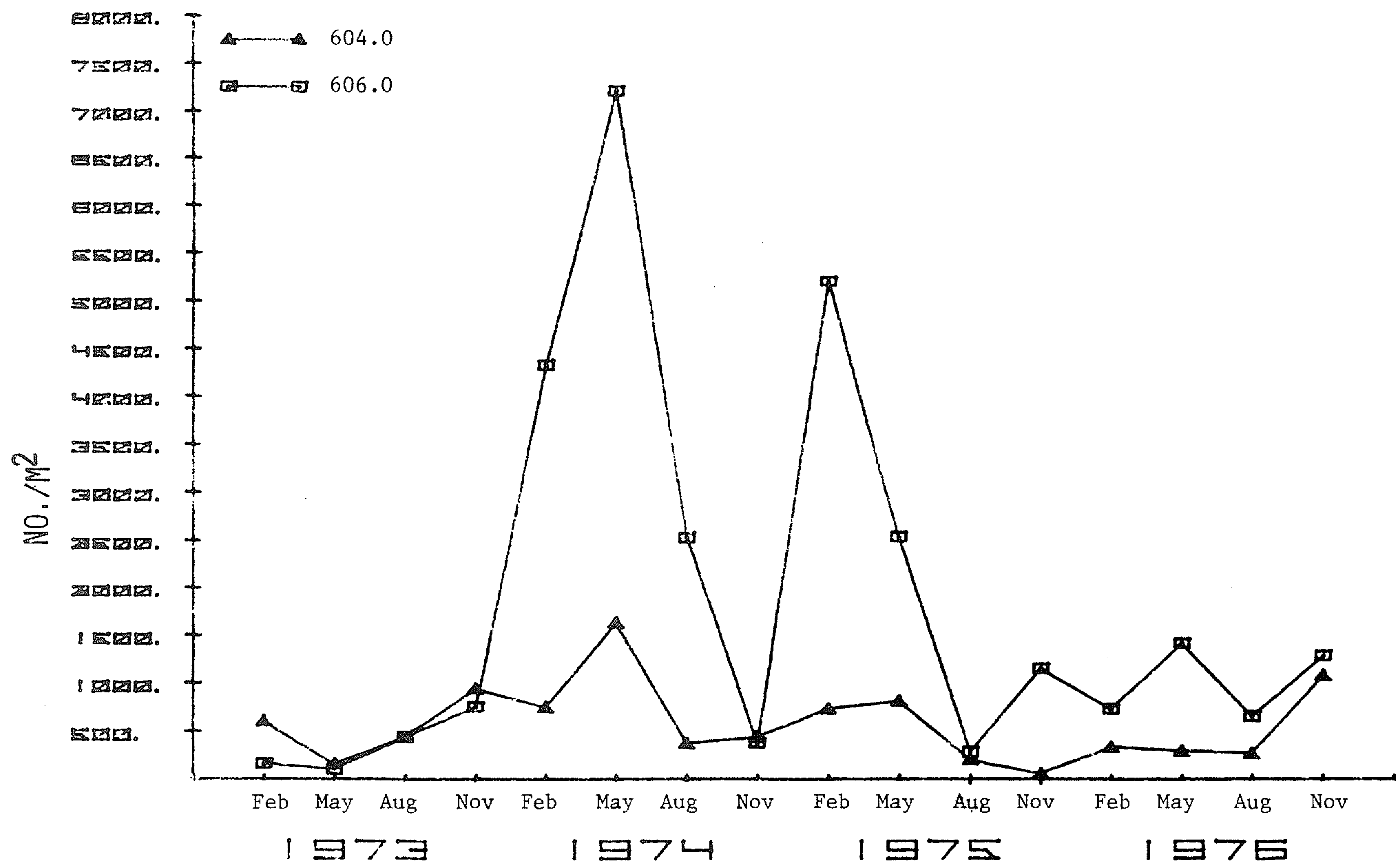


Figure 7-5. Mean density (no./m^2) of benthic macroinvertebrates at Locations 604.0 and 606.0 collected in grab samples from Lake Hartwell from February, 1973, to November, 1976.

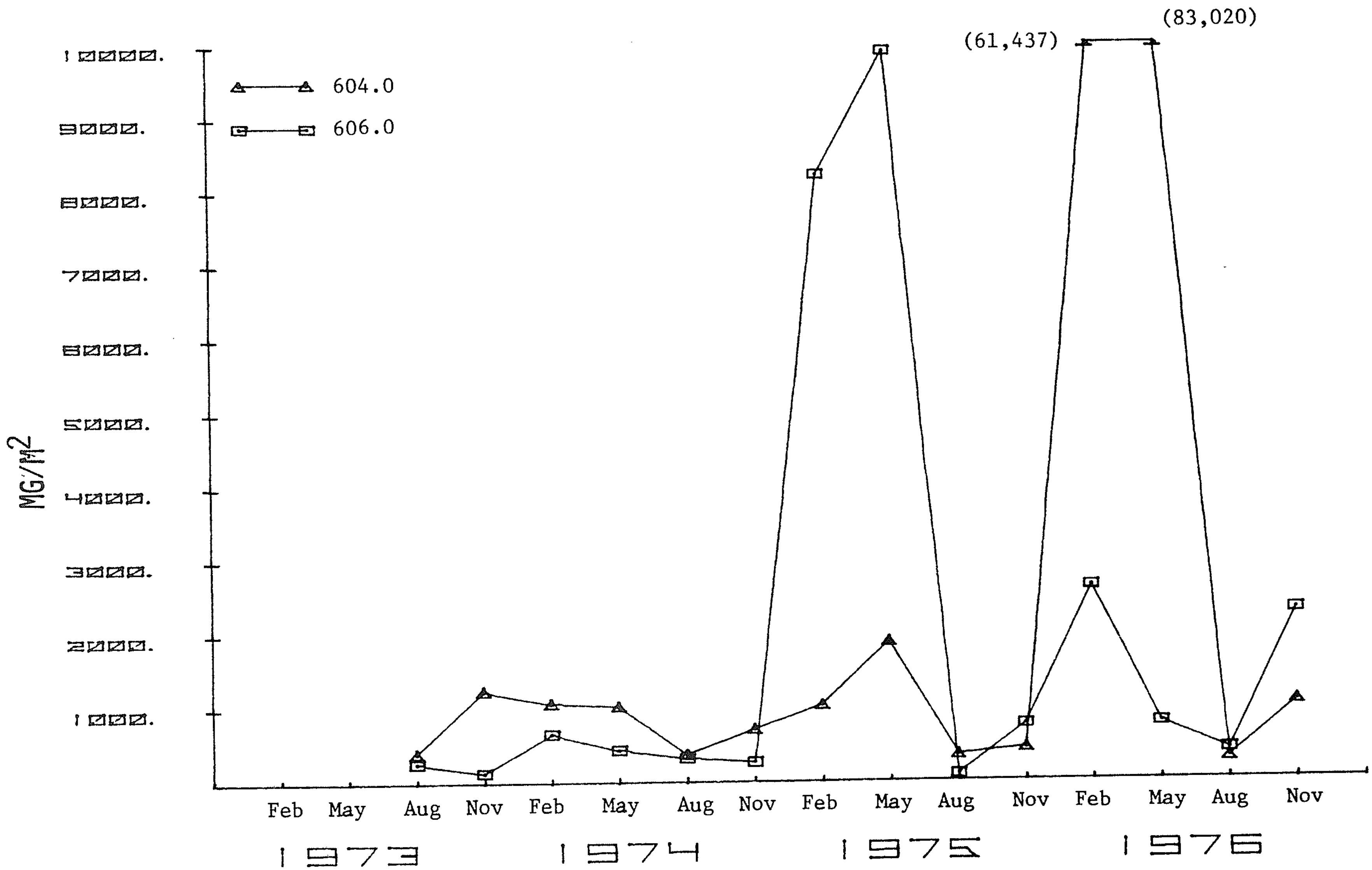
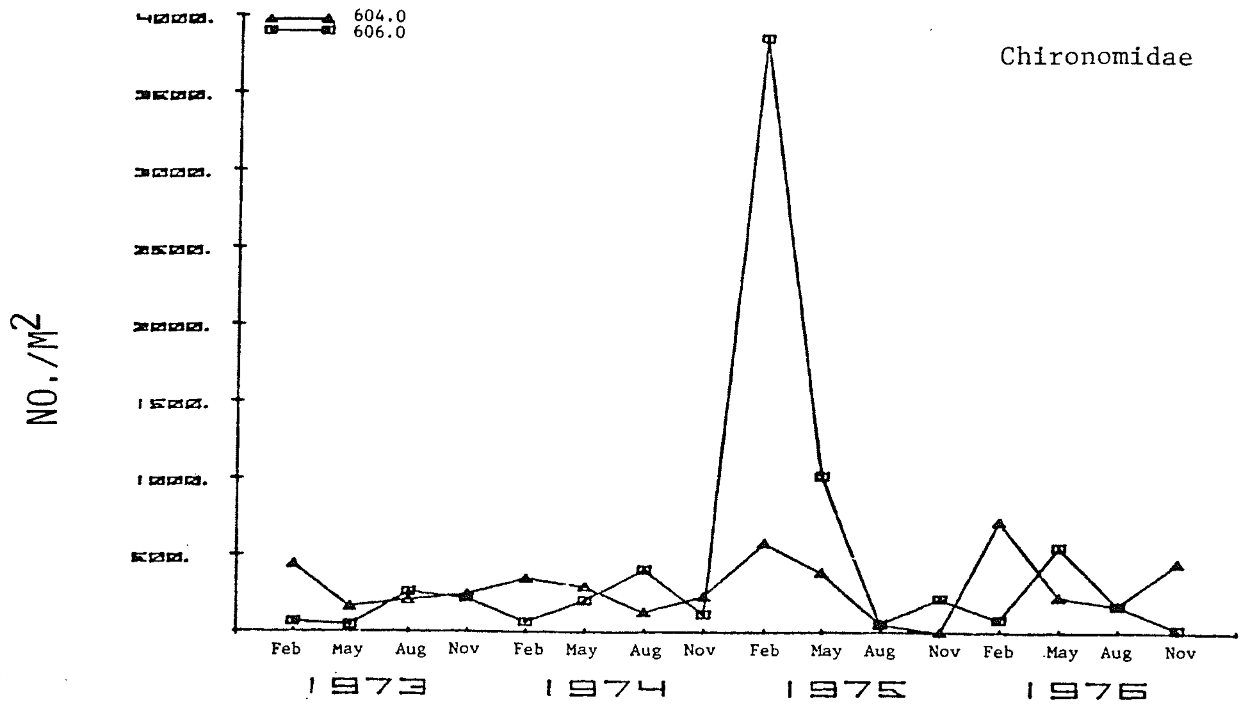


Figure 7-6. Mean biomass (mg/m^2) of benthic macroinvertebrates at Locations 604.0 and 606.0 in the sublittoral and profundal zones in Lake Hartwell from August, 1973, to November, 1976.



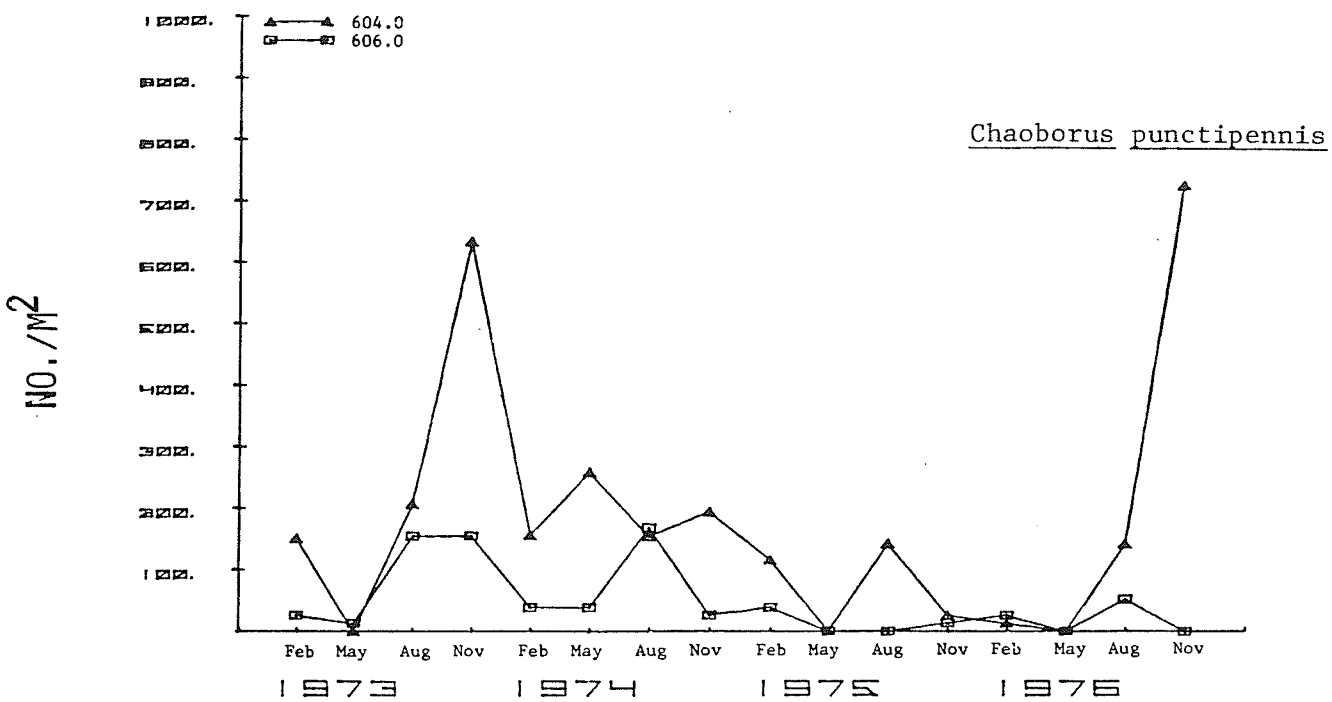
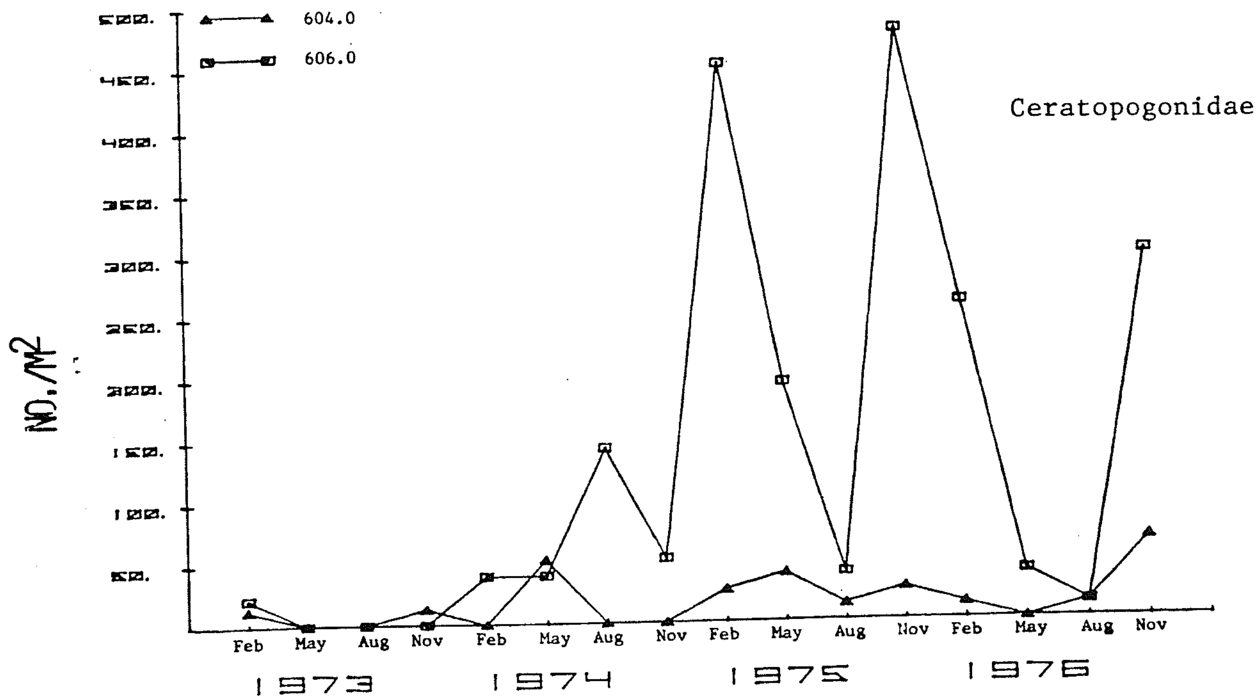


Figure 7-7. Mean density (no./m^2) of Chironomidae and Chaoborus punctipennis larvae at Locations 604.0 and 606.0 collected in grab samples from Lake Hartwell from February, 1973, to November, 1976.



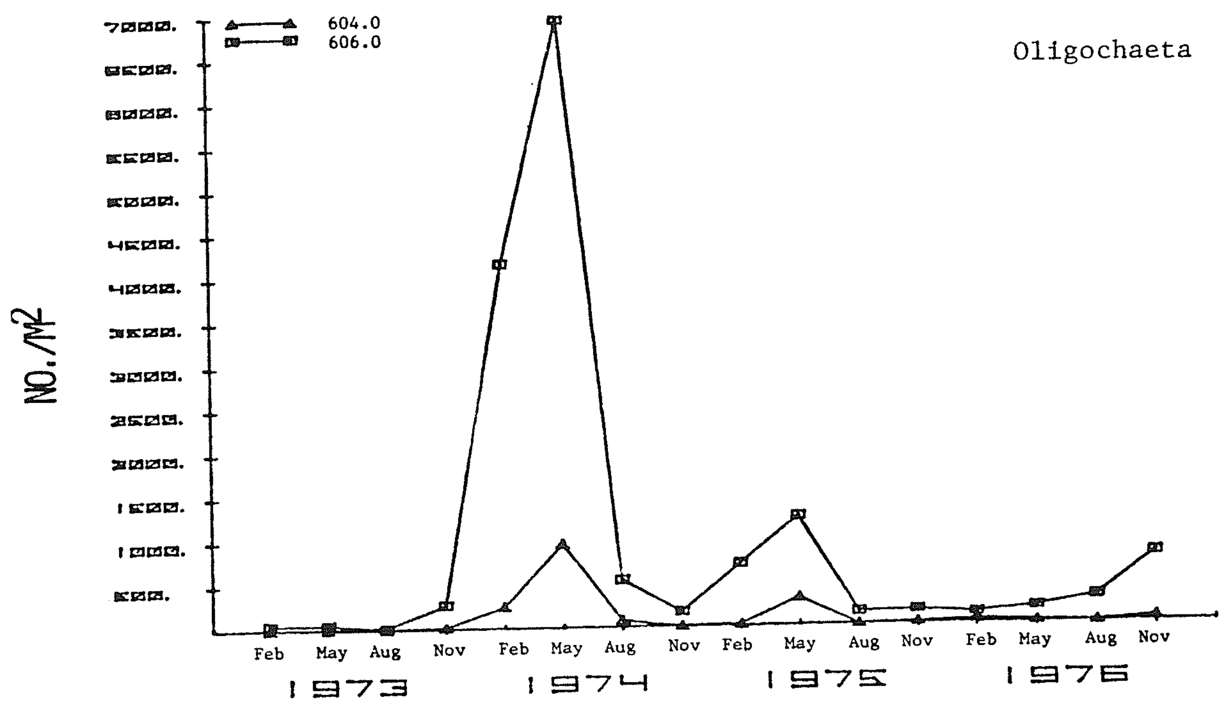
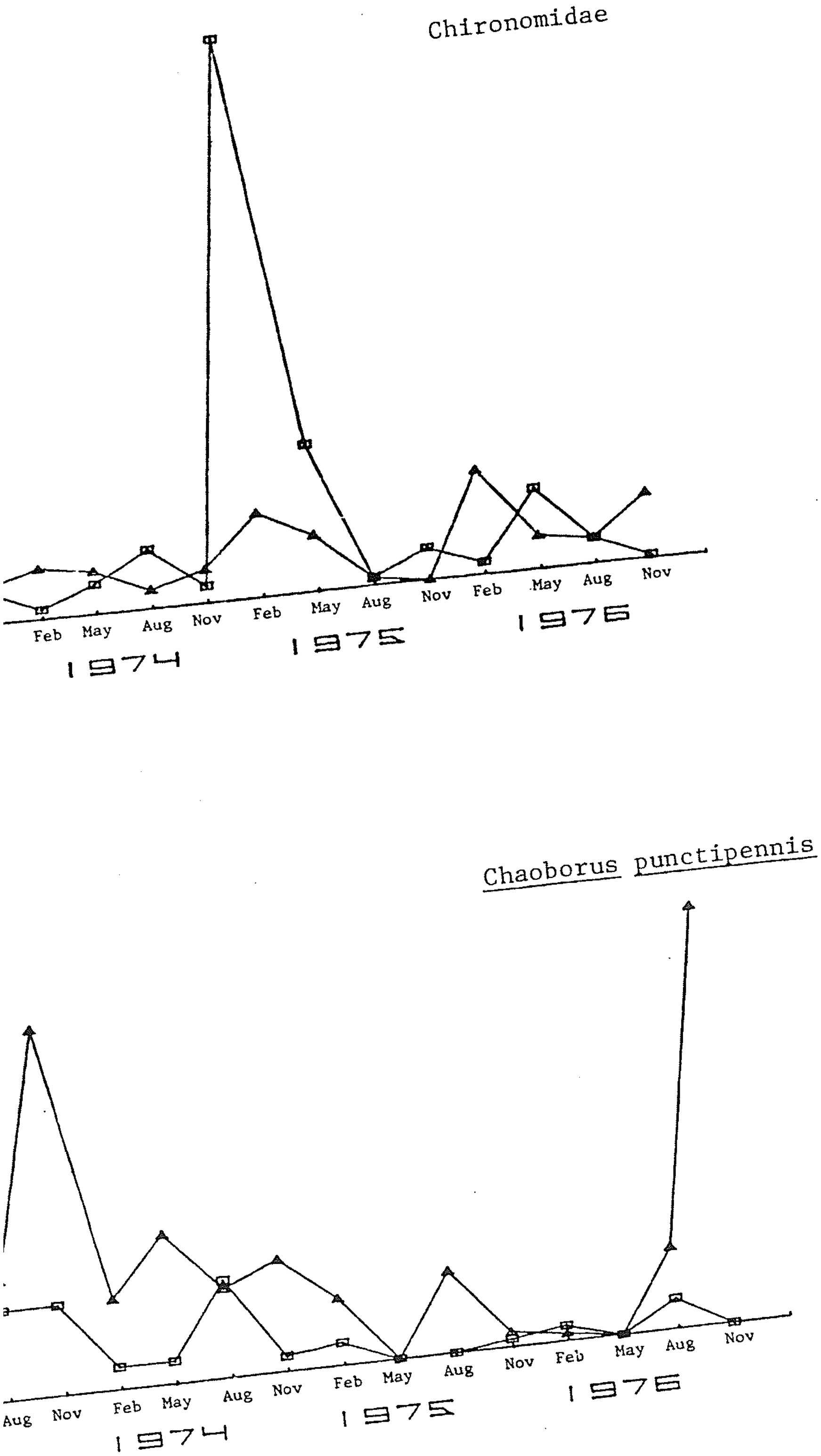
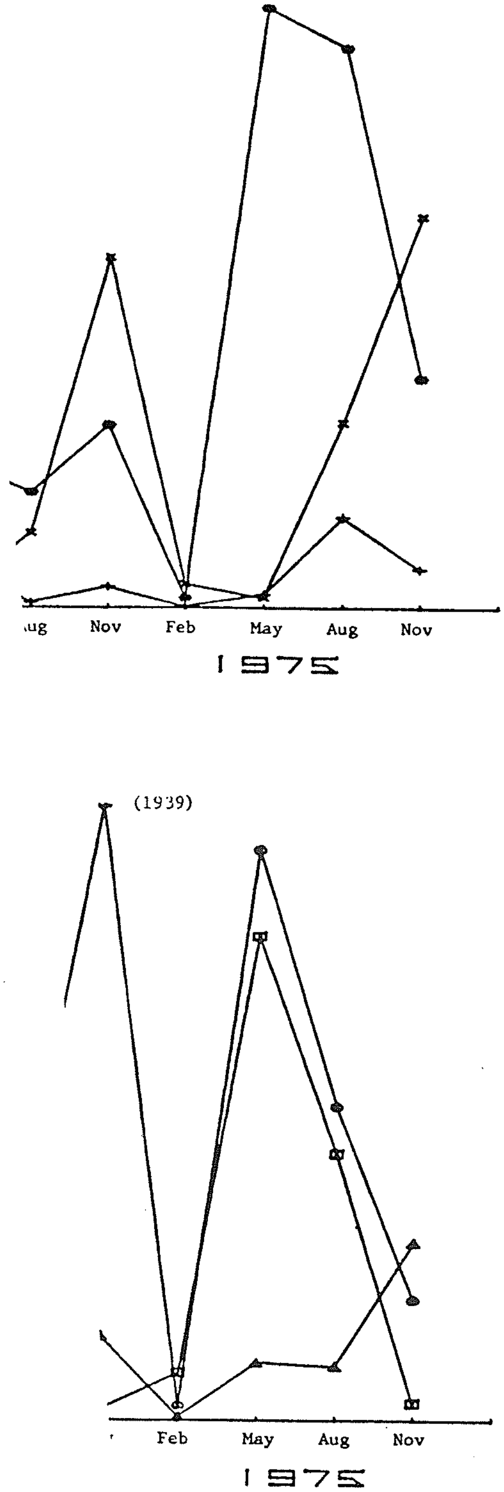


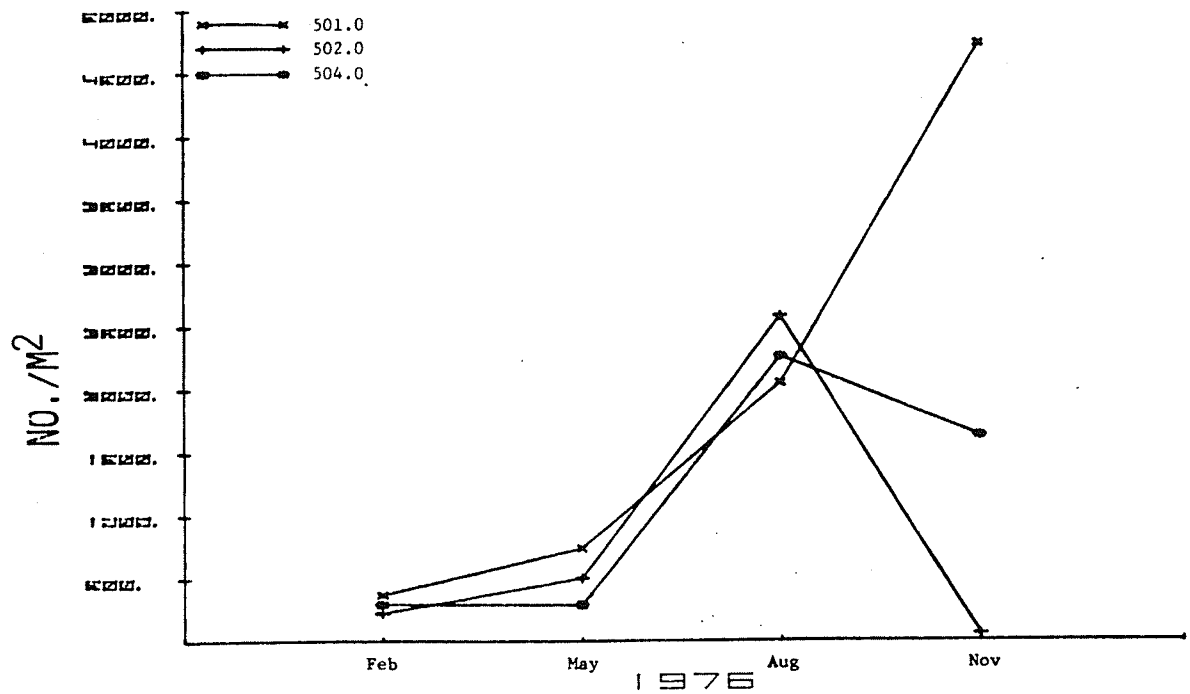
Figure 7-8. Mean density (no./m^2) of Ceratopogonidae larvae (<u>Palpomyia</u> complex) and Oligochaeta at Locations 604.0 and 606.0 collected in grab samples from Lake Hartwell from February, 1973, to November, 1976.



density (no./m^2) of Chironomidae and *Chaoborus*
ipennis larvae at Locations 604.0 and 606.0 collected
ab samples from Lake Hartwell from February, 1973, to
mber, 1976.



weep) of benthic
from February, 1973,



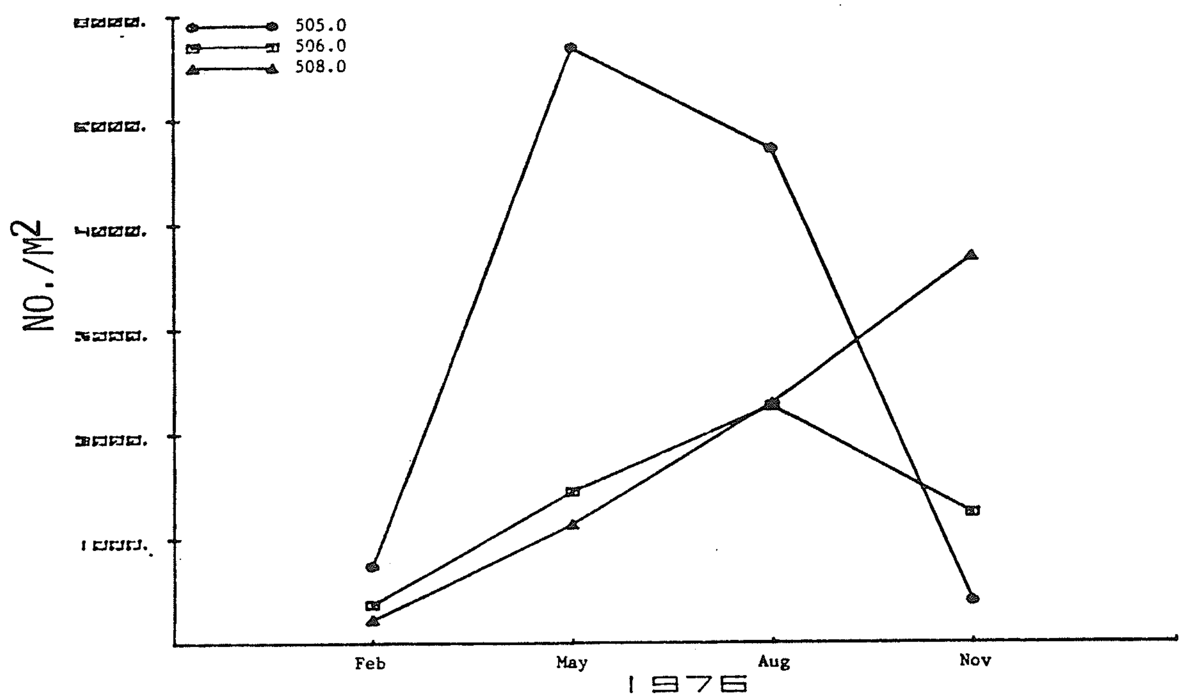
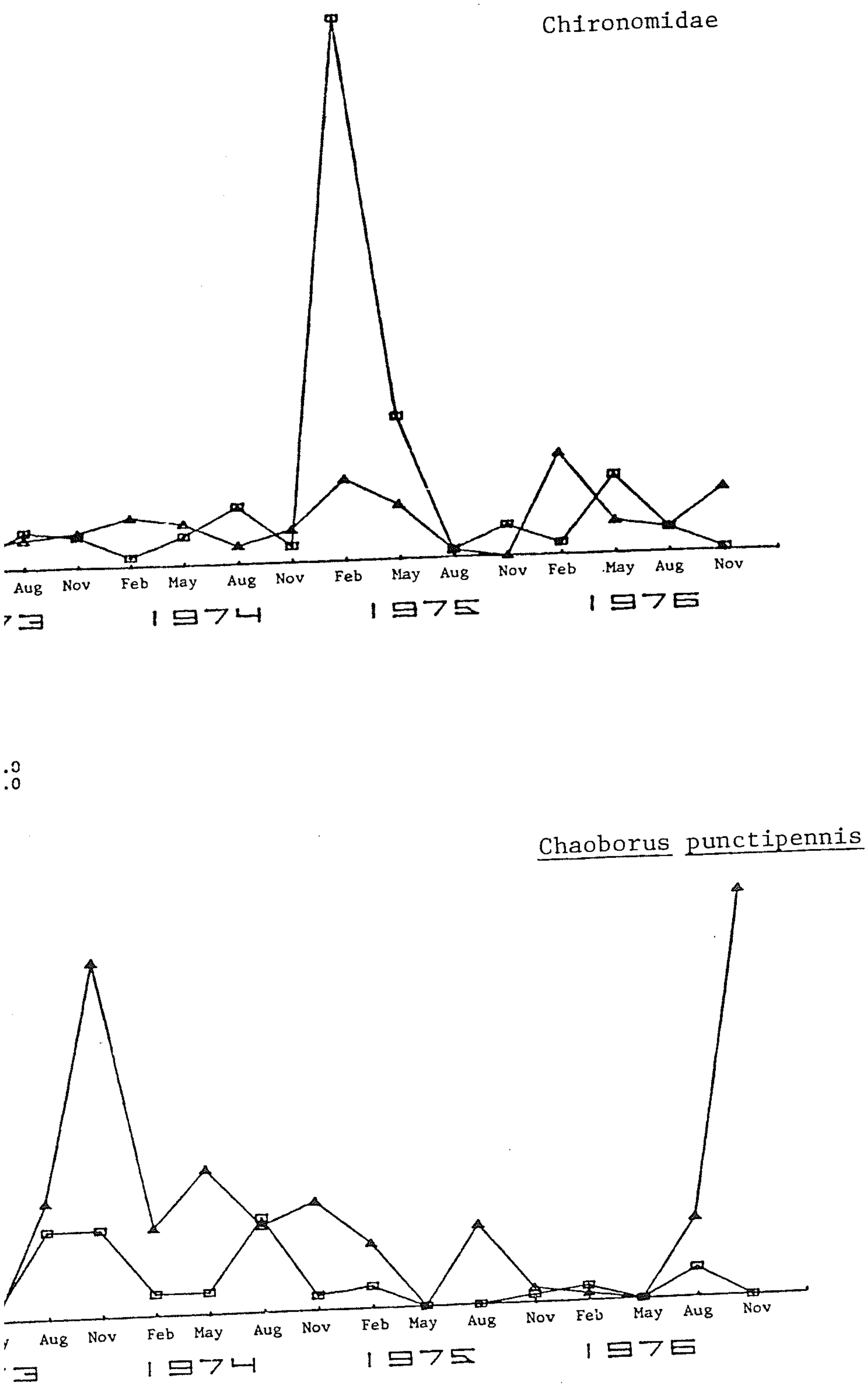
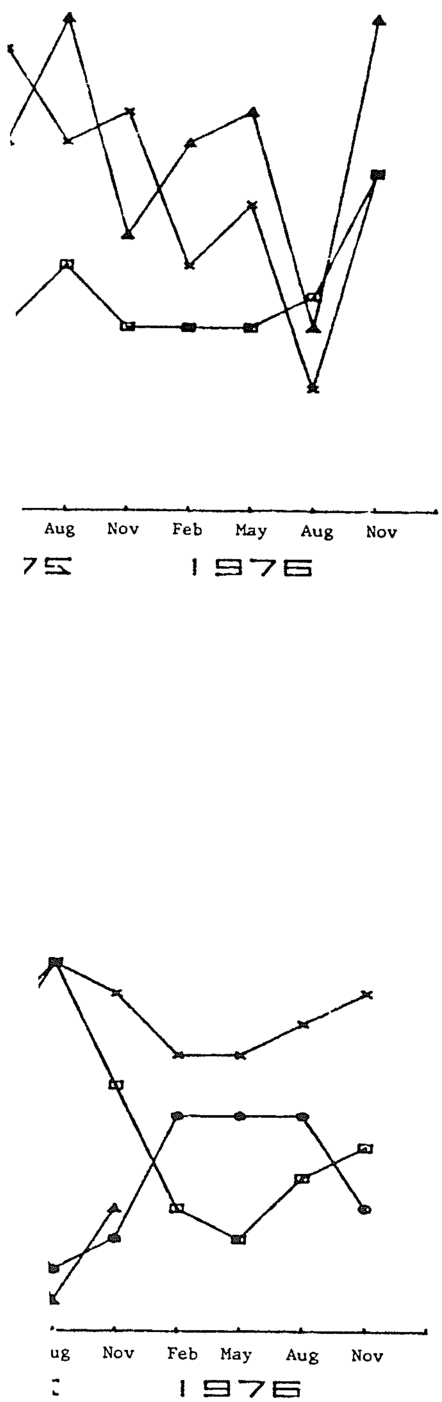


Figure 7-10. Mean density (no./m^2) of benthic macroinvertebrates collected in core samples from Lake Keowee in 1976.



n density (no./m^2) of Chironomidae and *Chaoborus*
ctipennis larvae at Locations 604.0 and 606.0 collected
grab samples from Lake Hartwell from February, 1973, to
vember, 1976.



) of benthic macro-
mples from Lake Keowee
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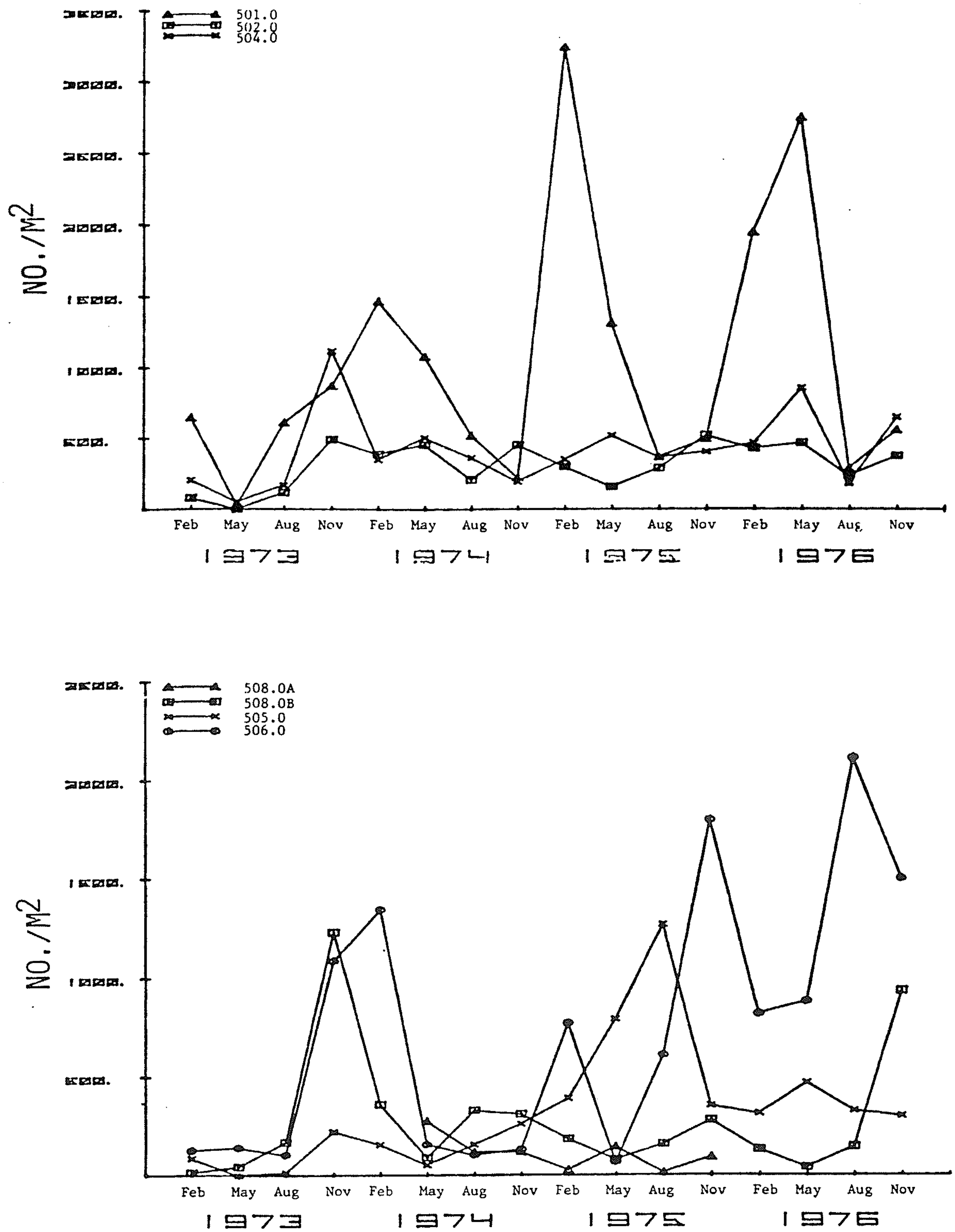
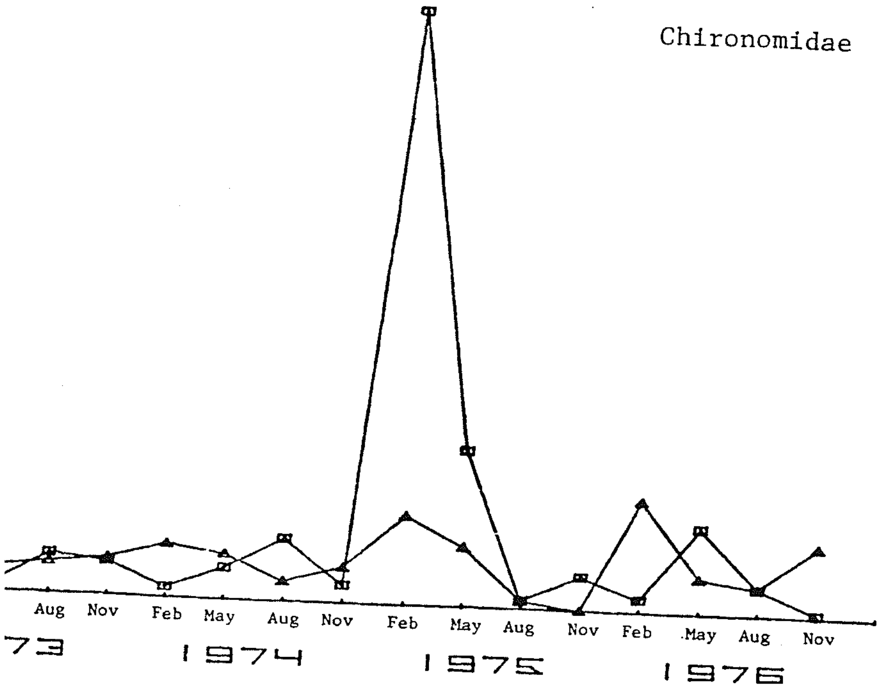
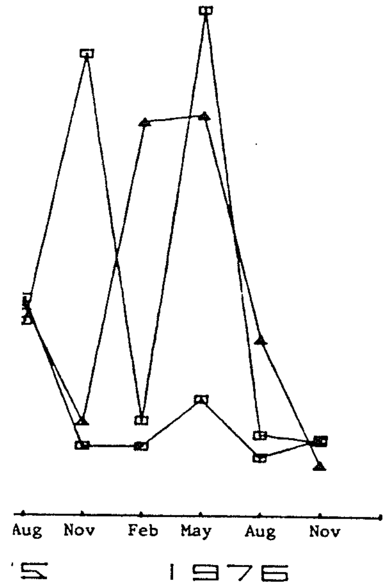


Figure 7-12. Mean density (no./m^2) of benthic macroinvertebrates collected in grab samples from Lake Keowee from February, 1973, to November, 1976.

604.0
606.0

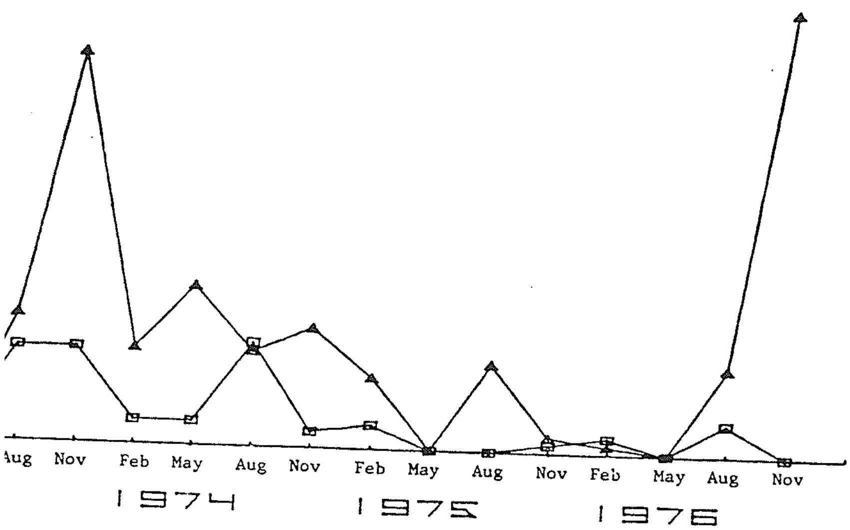
Chironomidae

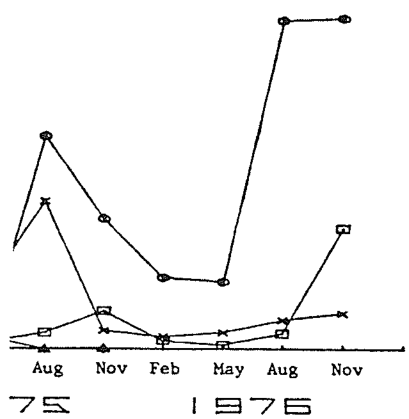




.0
.0

Chaoborus punctipennis





ensity (no./m^2) of Chironomidae and Chaoborus
pennis larvae at Locations 604.0 and 606.0 collected
ɔ samples from Lake Hartwell from February, 1973, to
er, 1976.

nacroinvertebrates collected
from August, 1973, to November,

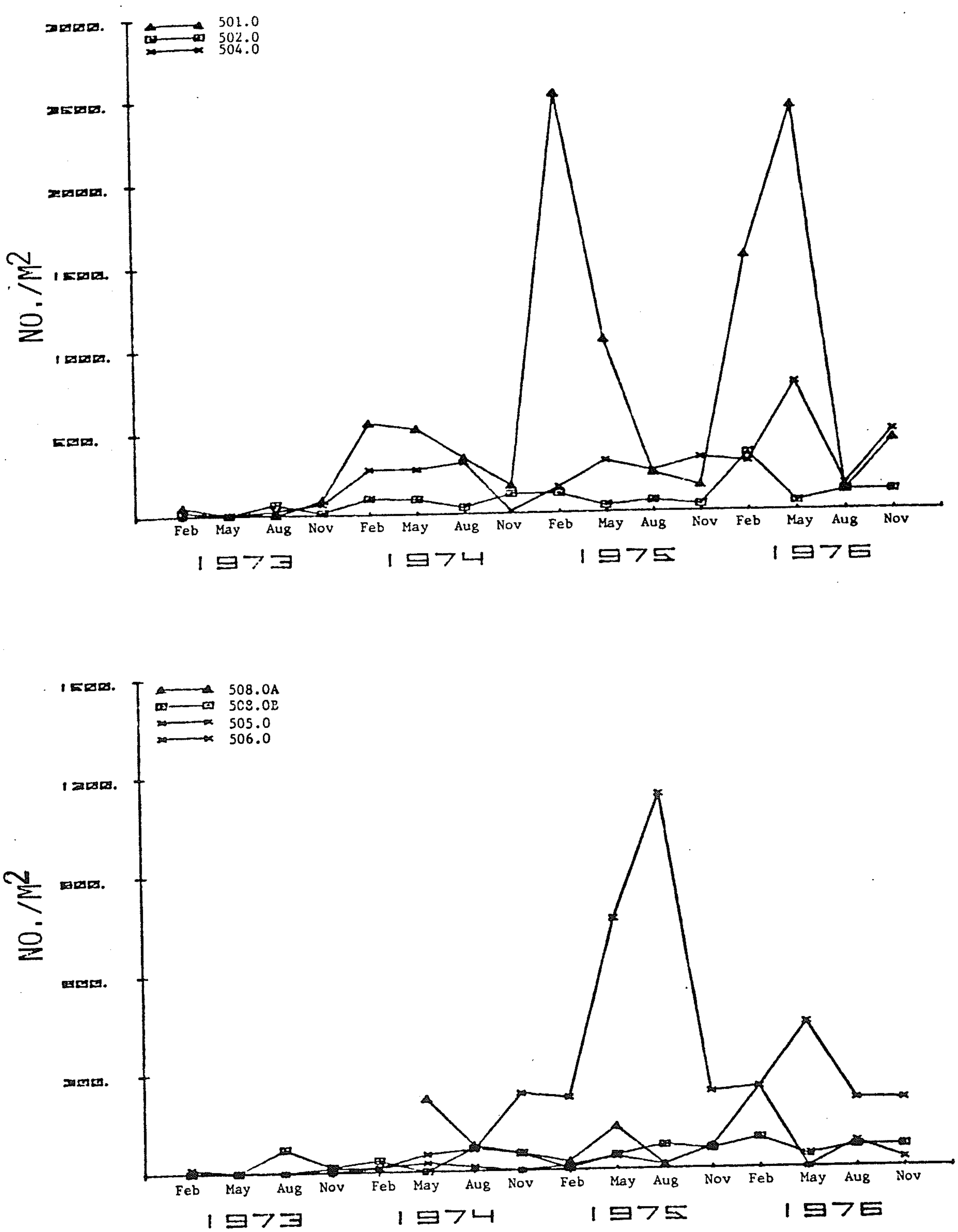
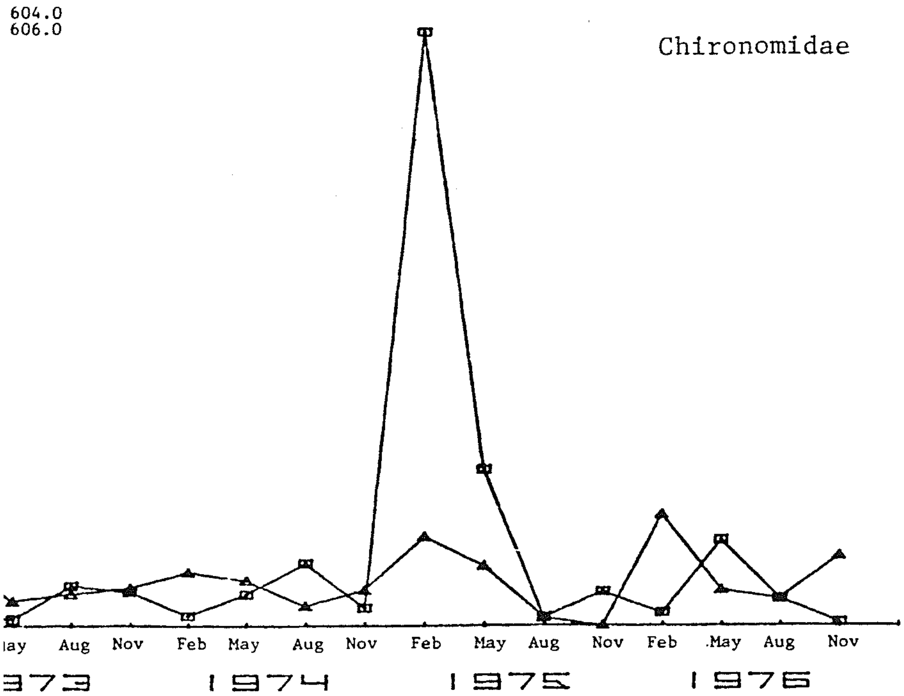
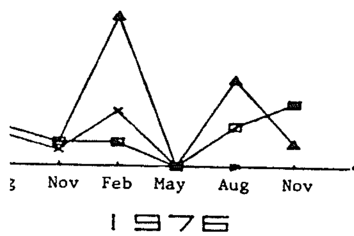
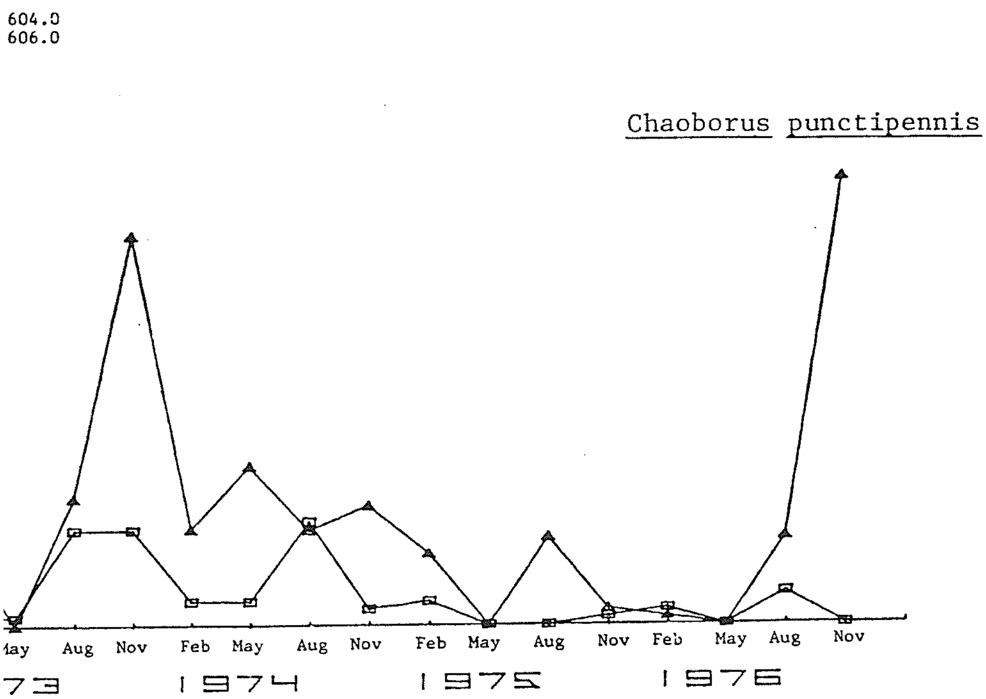
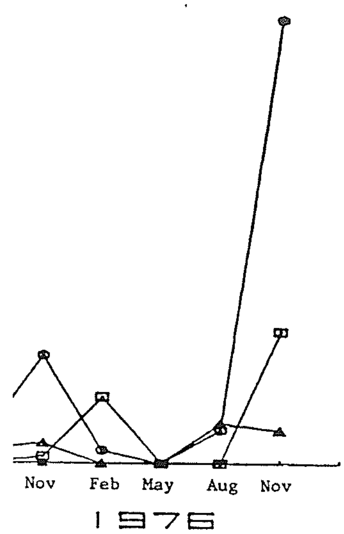


Figure 7-14. Mean density (no./m^2) of Chironomidae collected in grab samples from Lake Keowee from February, 1973, to November, 1976.



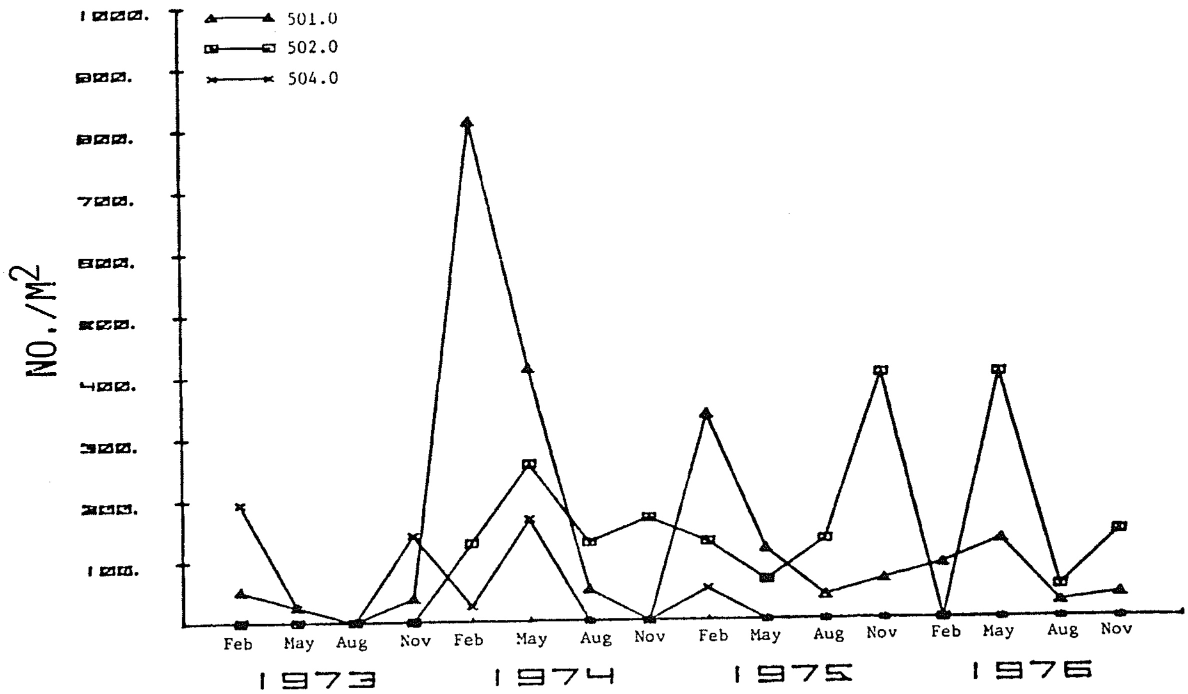






nctipennis larvae
eowee from February, 1973,

an density (no./m^2) of Chironomidae and _Chaoborus nctipennis_ larvae at Locations 604.0 and 606.0 collected grab samples from Lake Hartwell from February, 1973,to vember, 1976.



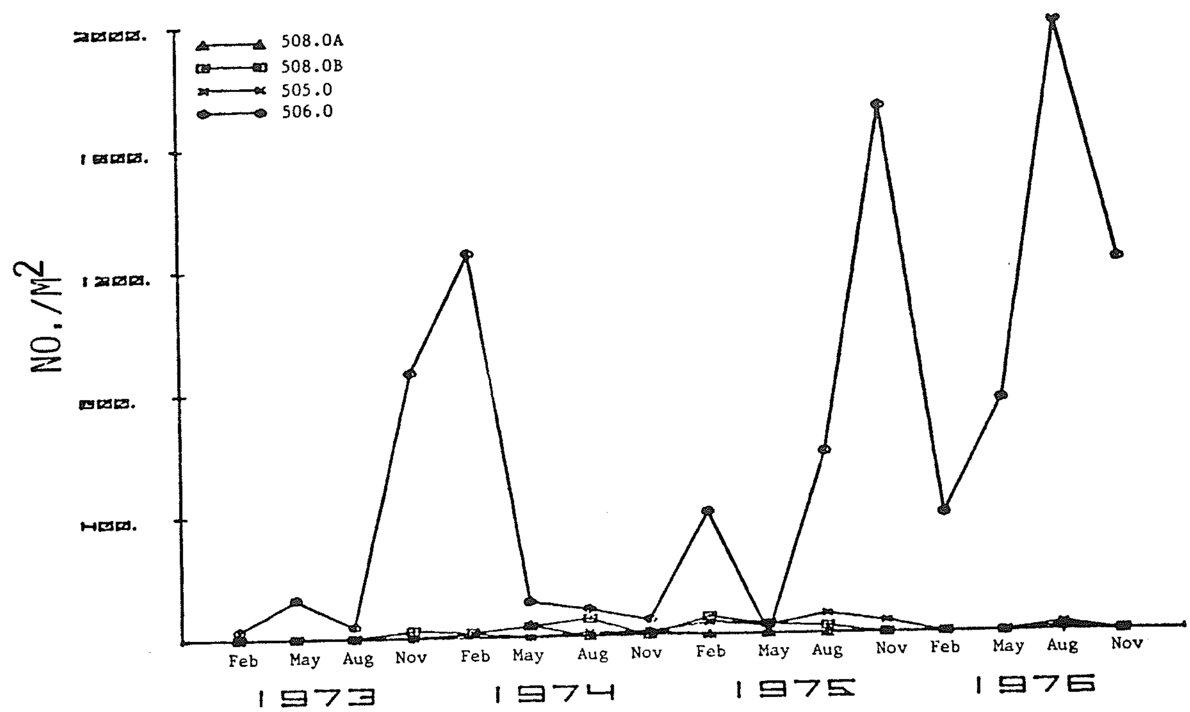
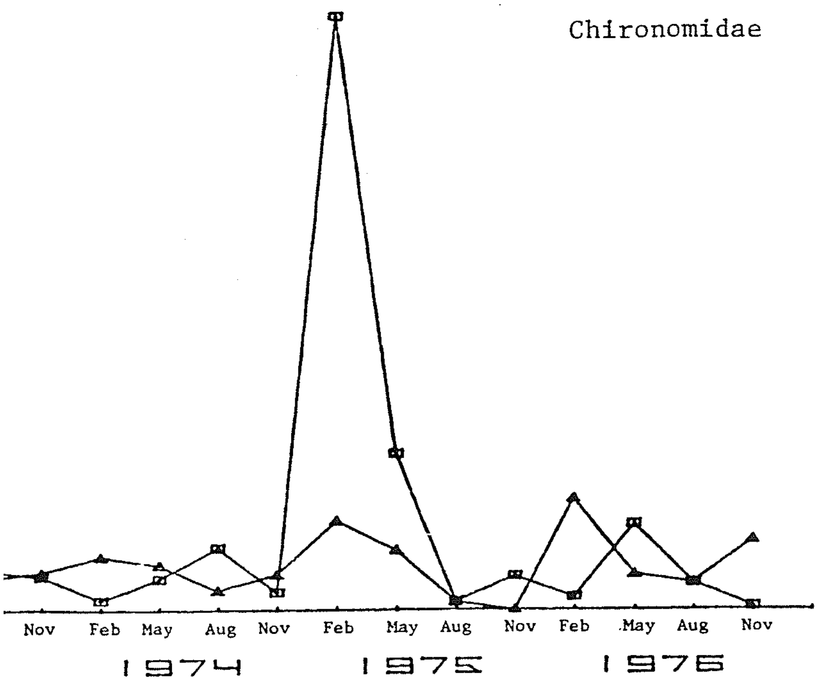
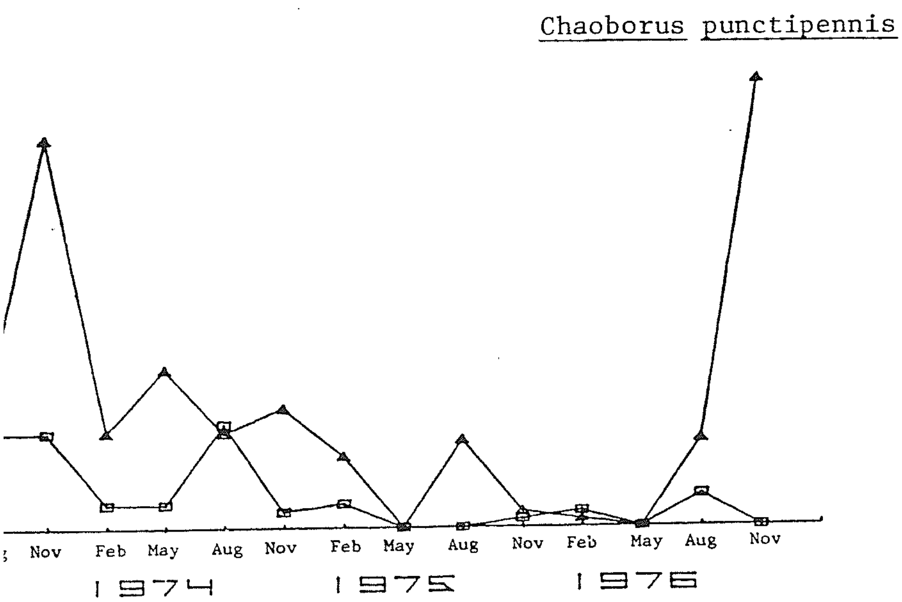


Figure 7-16. Mean density (no./m^2) of Oligochaeta collected in grab samples from Lake Keowee from February, 1973, to November, 1976.





nsity (no./m^2) of Chironomidae and *Chaoborus*
ennis larvae at Locations 604.0 and 606.0 collected
samples from Lake Hartwell from February, 1973, to
r, 1976.

CHAPTER 8

FISHERIES RESEARCH LAKE KEOWEE

I. INTRODUCTION

The fisheries research programs were designed and implemented to assess the environmental impact of ONS operations on the fish community in Lake Keowee. The objectives were: 1) to evaluate the effects of the ONS heated effluent upon the abundance, growth, and reproduction of the major fish species; 2) to determine the numbers and kinds of fish impinged upon the intake screens and the numbers and kinds of fish eggs and larvae entrained by the ONS Condenser Cooling Water (CCW) system; and 3) to determine the incidence and severity of gas-bubble disease among fishes in the heated effluent and to determine the associated percent saturation values of dissolved nitrogen and oxygen, in Lake Keowee.

FISH POPULATION DYNAMICS

Southeast Reservoir Investigations (SERI), U.S. Fish and Wildlife Service was established to evaluate long term effects of the operation of steam-electric generating stations and pumped storage hydroelectric plants on fish and other aquatic organisms in reservoirs. Much of this research has been on Lakes Keowee and Jocassee, and satisfies the first objective. In 1972 SERI began a multi-year study of the fish populations in Lake Keowee and the possible environmental impact of ONS operations upon the fishery resource of the lake. Two special summary reports and several other specific reports have been prepared by the Fish and Wildlife Service. These reports have been included as addenda to this chapter and are: 1) "Fish Populations in Keowee Reservoir, South Carolina, Prior to Nuclear Power Generation, 1968-1973" (Addendum A-1); 2) "Prediction of Fish Biomass, Harvest and Prey-Predator Relations in Reservoirs" (Addendum A-2); 3) "Summary of Fish Population Data from Keowee Reservoir 1972-1976" (Addendum A-3); 4) "Population Dynamics of Young-of-the Year Fish in a Reservoir Receiving Heated Effluent" (Addendum A-4); 5) Life History Studies Reports and Assembled Data (Addendum A-5); 6) Zooplankton and Benthos Studies in Keowee Reservoir, South Carolina (Addendum A-6); 7) Creel Census in Reservoirs (Addendum A-7); and 8) Abstracts of Theses Resulting from U. S. Fish and Wildlife Service Funded Research on Keowee Reservoir, South Carolina (Addendum A-8).

FISH IMPINGEMENT AND ENTRAINMENT OF FISH EGGS AND LARVAE

ONS requires a continuous supply of condenser cooling water for the operation of its once through lake cooling system. Water is drawn into the CCW system from the Little River arm of Lake Keowee and discharged to the Keowee River Arm (Figure 1-1). The skimmer wall (Figure 1-4) across the entrance to the intake canal allows cooling water to be drawn from a depth of 20 to 27m (the opening at the base of the skimmer wall) from full pool. Shortly after entering the 1.5-km intake canal the water passes over a submerged weir (Figure 1-4) as it flows toward the intake structure. The intake structure provides support for the trash racks, fixed intake screens (1-cm mesh openings) and CCW pumps. There are twelve CCW pumps (4 pumps for each of the three nuclear units) with each pump having two inlet bays and each inlet bay having a stationary screen. The intake screens, positioned between trash racks and the CCW pump-wells, are located at a depth of 5.6 to 11.9 m from full pool. At full pool the intake water velocities at the screens range from 26.8 cm/sec for 4 pumps/unit operation to 36.3 cm/sec for 2 pumps/unit operation.

Loss of fish due to impingement on the CCW intake screens represents a potential impact on the fishery resources of Lake Keowee. In addition, the operating efficiency of ONS can be impaired by reduced pumping efficiency of the CCW pumps due to the accumulation of fish and debris on the screen surfaces. To determine the mortality of fish impinged upon the intake screens, five related studies have been conducted for various periods since June 1973. These studies were: 1) weekly visual inspections from the intake structure; 2) quarterly inspection of screens by SCUBA; 3) inspection of screens pulled due to reduced CCW pumping efficiency; 4) bi-weekly inspection of representative screens for quantitative assessment of fish impingement; and 5) quarterly screen inspections of representative screens for seasonal impingement rates.

Loss of fish eggs and larvae due to entrainment in the CCW system represents a potential environmental impact upon the fishery resource of Lake Keowee. Fish eggs and larvae passing through the CCW system are subjected to mechanical effects from pumping, pressure, abrasion and thermal effects from a rapid increase in temperature. Two studies have been conducted to establish the extent to which fish eggs and larvae are entrained through the CCW system. The first study was designed to monitor entrainment within the CCW system. Sampling within the CCW system during the spawning periods of 1973 and 1974 indicated few, if any, fish eggs and larvae were being entrained (Duke Power Company 1973a, 1973b, 1974a and 1974b). Therefore, a second study was implemented in 1975 to determine the numbers and kinds of fish eggs and larvae being withdrawn under the skimmer wall into the intake canal and also to determine the extent of reproduction of fishes inhabiting the intake canal.

GAS BUBBLE DISEASE AND SUPERSATURATION OF DISSOLVED GASES

Gas bubble disease (GBD) is a syndrome affecting fish exposed to water supersaturated with dissolved gases. This condition has long been recognized as a danger to fish (Marsh and Gorham, 1905; Woodbury, 1941; Pauley and Nakatani, 1967). The disease is most commonly recognized in fish exhibiting external symptoms such as extrusions of the eyes ("popeye") and bubble formations under the integument, in the fins, gills, and roof of the mouth. Bubble formation in the blood stream of fish may result in blockage of capillaries which may lead to death.

Although nitrogen is generally accepted as being the prime cause of GBD in fish because of its low solubility and because it is not readily removed from the dissolved state by blood components, other atmospheric gases have been cited as contributing to the GBD phenomenon (Rulifson and Abel, 1972; Rucker, 1972). Rucker (1972) states in his critical review of GBD in salmonids that "oxygen can cause gas-bubble disease at about 350% air saturation, but nitrogen can cause the disease even below 118% air saturation."

The occurrence of GBD is most commonly associated with large hydroelectric facilities which have water cascading into plunge basins (Rulifson and Abel, 1972; Bouck, et al. 1970; Ebel, 1969). However, it was not until the early 1970's that the occurrence of the disease was associated with the thermal effluent of steam generating stations (Demont and Miller, 1971; Marcello and Strawn, 1972; Adair and Hains, 1973; Otto, 1976). Demont and Miller (1971) found that 13 species of fishes inhabiting the discharge canal and cove of Marshall Steam Station on Lake Norman, North Carolina exhibited external symptoms of GBD. Adair and Hains (1973) and Miller (1973) presented data associating GBD with nitrogen supersaturation in the discharge areas of Marshall Steam Station. Marcello and Strawn (1972) discovered that several marine species of fish developed GBD when held in the discharge canal of a steam-electric generating station in Galveston Bay, Texas. Otto (1976), in research on Lake Michigan in the discharge areas of two electrical generating stations (Waukegan and Zion), discovered that water passing through the condenser cooling water systems of these two stations became supersaturated with nitrogen gas as high as 130 percent. However, studies of the fish populations in the discharge areas revealed no symptoms of GBD. Otto concluded that the fish did not remain in the discharge canals long enough to develop the disease.

Saturation levels of oxygen and nitrogen associated with power plant discharges are of concern because levels of saturation vary with changes in temperature. The solubility of gases, to a large extent, is inversely proportional to temperature and directly proportional to changes in pressure.

Supersaturation occurs when water saturated with dissolved gases undergoes an increase in temperature without a corresponding loss in gases (Harvey and Smith, 1961; Snyder, 1969). This situation characterizes the process of lake water passing through the CCW system of a steam generating station. In order to evaluate the possibility of gas-bubble disease occurring in association with the operation of ONS, the percent saturation of oxygen and nitrogen was determined at selected locations during the winter months (November-April). To determine the incidence of GBD in the thermal discharge area, SERI routinely examined fishes for GBD symptoms.

II. METHODS AND MATERIALS

FISH POPULATION DYNAMICS

See Addenda A-1, A-2, A-3, A-4, A-5, A-7, and A-8.

FISH IMPINGEMENT ON INTAKE SCREENS

The weekly visual inspections for indications of large scale fish impingement were conducted from June 1973 through April 1976. Direct observations were made from the intake structure by inspecting each of the 24 CCW pump forebays for fish floating on the lake surface. Observed fish were identified to species, counted and sizes estimated.

The quarterly inspection of screens for fish impingement using SCUBA was conducted from June 1973 to March 1976. A minimum of two screens per unit were inspected each quarter. Impinged fish were identified to species (when possible), counted, and sized.

Periodically the intake screens were pulled because of reduced pumping efficiency of the CCW pumps due to a build-up of debris and/or fish upon the screen surfaces. Each time a screen was removed for cleaning, impinged fish were identified (when possible), counted and sized.

The inadequacy of the three monitoring programs above to quantitatively assess fish impingement at ONS prompted bi-weekly (once every two weeks) inspections of representative screens from May 2, 1974 to May 9, 1975. Two screens from each unit (1A1, 1A2, 2A1, 2A2, 3A1, and 3A2) were pulled and inspected on twenty-six occasions during the study period. Impinged fish were identified to species, counted and sized. Subsampling was utilized where large numbers of threadfin shad covered the entire screen surfaces uniformly. The subsample consisted of identifying, counting and sizing all of the fish on one of the six screen panels and multiplying by six to obtain the individual screen totals.

Following the one year quantitative assessment of fish impingement, quarterly screen inspections of the same six intake screens were conducted to monitor seasonal rates of impingement. The quarterly inspection consisted of pulling the six screens; recording the species, numbers, and lengths of impinged fish; cleaning the screens thoroughly; placing the screens back in position; and operating the associated CCW pump for a period of seven days. At the end of the seven day period the same screens were inspected again, and impinged fish were identified, counted, and sized. Seasonal impingement rates were computed for the seven day accumulation period preceding each quarterly inspection.

ENTRAINMENT OF FISH EGGS AND LARVAE

Monitoring of the CCW system for entrainment of fish eggs and larvae was accomplished by sampling cooling water from the Unit 1 pre-condenser outlet bi-weekly (every two weeks) during the major spawning period of Lake Keowee fishes (at minimum April through July). A flow rate from the pre-condenser outlet was established for each sample by measuring the amount of time required to fill a 0.21 m^3 drum. A 500 micron mesh nylon net suspended in the drum was used to filter the required minimum volume of cooling water (3.8 m^3). Once the sample was collected, the filtrate was taken to the laboratory and examined for fish eggs and larvae. Beginning in 1974, the sampling frequency was increased to weekly and in 1975 sampling duration was increased to 24 hours.

During the spawning seasons of 1975 and 1976, weekly daytime sampling for fish eggs and larvae within and entering the ONS intake canal was implemented. A nylon net (500 micron mesh), one meter in diameter and equipped with a flow meter, was suspended in the flow of water passing through the opening in the skimmer wall to sample the fish eggs and larvae entering the intake canal. Sampling in the intake canal consisted of trawling with similar gear. Two 15 minute surface hauls and two 15 minute hauls at 5 m were collected from the intake structure to the skimmer wall and preserved in formalin. Sample volumes were calculated using flow meter revolutions and the area of the openings in the nets. Fish eggs and larvae were counted and identified to species.

GAS-BUBBLE DISEASE AND SUPERSATURATION OF DISSOLVED GASES

To determine the prevalence and severity of GBD in Lake Keowee fishes, SERI has periodically collected fish by gill netting and electroshocking in the Oconee Nuclear Station discharge area as well as other areas throughout the lake since 1972. Fish were examined for external symptoms of GBD.

Monthly water sampling was implemented in November, 1973 to monitor the percent saturation values of oxygen and nitrogen in the waters of Lake Keowee. Since supersaturation is primarily related to winter conditions, when ambient dissolved gas levels are most likely to be near the saturation level (Miller and Demont, 1972; Adair and Hains, 1973; and Otto, 1976) sampling was carried out only during the period November through April of each year. Water samples were obtained from four depths (0.3, 1.5, 3.0, and 6.1 meters) at eight sampling locations on Lake Keowee: 501.0, 502.0, 530.0 (Intake), 530.9 (Discharge), 508.0, 503.0, and 504.0 and 505.0 (Figure 1-1). The samples were collected using 15 ml serum bottles placed in a sewage sampler and lowered to a specified depth. When the sewage sampler filled with water, it was pulled to the surface, the top removed, water temperature measured, and the serum bottle closed under water with a rubber serum cap. All samples containing air bubbles were discarded until a sample free of air bubbles was obtained. The samples were then placed in a water bath at approximately the sample temperature. Samples were taken to the lab for analyses as soon as possible after collection.

A number of techniques have been described for the analysis of dissolved gases (Rucker, 1962). For this study a technique similar to the one developed by Swinnerton et al. (1962) was used. A Model II Dissolved Gas Analyzer (modified gas chromatograph) manufactured by Allen Science Research, Inc. was used for the determination of dissolved nitrogen and oxygen quantities. Accuracy of the instrument is $\pm$ 5% with good standards. The quantity of gas in the sample is directly proportional to the area under the curve generated by that gas. High purity helium was used as the carrier gas.

A 5 ml subsample was drawn from each serum bottle using a syringe and injected individually into the gas chromatograph for analysis. The area under the curves, generated by the two gases (nitrogen and oxygen), was determined using a Model 485, Varian Electronic Digital Integrator. The sample areas were then compared with standard areas (generated from saturated distilled water at room temperature) using the following formulae for determining gas concentrations and percent saturations:

$$\text{Sample Concentration (mg/l)} = \frac{\text{(Sample Area) (Gas Concentration of Standard at Standard Temperature)}}{\text{Standard Area}}$$

$$\text{\% Saturation} = \frac{\text{Sample Concentration} \times 100}{\text{Concentration of Gas at Saturation at Sample Temperature}}$$

Where: The concentration of Gases (Nitrogen and Oxygen) at saturation for various temperatures was obtained from solubility tables (Weiss, 1970).

III. RESULTS AND DISCUSSION

FISH POPULATION DYNAMICS

See Addenda A-1, A-2, A-3, A-4, A-5, A-7, and A-8.

FISH IMPINGEMENT ON INTAKE SCREENS

Weekly Visual Inspections From the Intake Structure

No fish were observed during the 1973 inspections. In 1974 a total of 22 fish were observed. The species observed included seven bluegill (*Lepomis macrochirus*), four yellow perch (*Perca flavescens*), five largemouth bass (*Micropterus salmoides*), four carp (*Cyprinus carpio*), and two black crappie (*Pomoxis nigromaculatus*). The majority of fish were less than 10 cm in length. In 1975 a total of 118 fish were observed floating in the forebays, all of which were less than 10 cm in length. The numbers of fish by species were 10 bluegill, 5 yellow perch, and 103 threadfin shad (*Dorosoma petenense*). During the first four months of 1976 one hundred forty-three threadfin shad, less than 8 cm in length, were observed floating in the forebays (Table 8-1).

In April, 1976 Duke Power Company received permission from the Nuclear Regulatory Commission to delete the weekly visual inspections because: 1) observations from the intake structure did not adequately assess fish impingement at ONS; 2) the intake screens are not visible from the top of the intake structure; and 3) fish floating on the lake surface in the forebays probably had been impinged on the intake screens and had been dislodged by the back-flow of a CCW pump taken out of service.

Quarterly Inspection of Screens by SCUBA

A total of 43,845 impinged fish (35,877 identified) was recorded for the 12 quarterly SCUBA inspections during the period June 1973 through

March 1976 (Table 8-2). Species composition and percent of total identifiable fish were: 1) threadfin shad (81.9%); 2) bluegill (10.3%); 3) yellow perch (7.7%); 4) largemouth bass (0.04%); and 5) miscellaneous species (0.06%). The numbers of impinged fish were relatively low from June 1973 until November 1974. By December 1974 and January 1975, only 10 months after S.C. Wildlife and Marine Resources Department had introduced threadfin shad into the lake, large numbers were being impinged on the intake screens. The susceptibility of threadfin shad to water temperatures less than 8 C^{o} (Parson and Kimsey, 1954; Strawn, 1965) coupled with their attraction to the skimmer wall and subsequent entrance into the intake canal, accounted for the large increase in numbers of fish being impinged. In 1975 and 1976 the same trends were found, low numbers of fish were impinged during the spring, summer, and fall, and large numbers of threadfin shad were impinged during the winter.

Although the quarterly inspections of intake screens by SCUBA provide a seasonal assessment of fish impingement, the determination of impingement rates is impossible due to the length of time between inspections. As a result Duke Power Company received permission from the Nuclear Regulatory Commission in April, 1976 to delete the SCUBA inspections.

Inspection of Screens Pulled Due to Reduced CCW Pumping Efficiency

Impingement data recorded during the non-scheduled inspections of intake screens are incorporated into Table 8-3. Periodically, screens have been pulled and cleaned simply because a build-up of debris (leaves and/or fish) restricts the flow of cooling water into the CCW system. Data accumulated during these infrequent screen inspections are similar to those presented for the SCUBA inspections. No attempt will be made to discuss the results of these inspections since the data are limited and highly variable.

Bi-Weekly Inspection of Representative Screens

Data on fish impingement rates were determined by the comprehensive one year study that was implemented in May 1974. A summary of the species, numbers, and sizes of fish impinged upon six of the twenty-four intake screens is presented in Table 8.3. Total ONS impingement rates remained relatively low during the period May 2 through October 31, 1974 (average of 238 fish per day). Bluegill and yellow perch were the species most commonly impinged (99.1% of identifiable fish). Almost all impinged fish were 10 cm or less in length (99.5%). During the period November 7, 1974 through April 24, 1975, twelve bi-weekly inspections reported a total of 144,586 fish (94,037 identified) impinged on the six intake screens (a rate of 3,195 fish impinged per day for all 24 screens combined). Species composition and percent of total identifiable fish were as follows: threadfin shad (94.5%), yellow perch (4.8%), bluegill (0.6%), and miscellaneous species (<0.1%). Most (99.9%) of the impinged fish were 10 cm or less in size. The successful introduction of threadfin shad into Lake Keoweee in January and February 1974 was apparent by November 1974 when low numbers of the species were being impinged on the intake screens. The susceptibility of threadfin shad to cold winter temperatures and their movement into the intake canal became evident in January, February, and March of 1975 when the winter temperatures in the intake canal dropped to a low of 8.9 C and the average impingement rate increased to 15,168 threadfin shad per day (Figure 8-1). In May 1975, the end of the bi-weekly inspections, the numbers of fish impinged during the 14 day accumulation period (ending May 9) dropped to 26 fish for the 6 screens inspected, as compared to 95 during a similar period the previous year.

Quarterly Screen Inspection

With the conclusion of the one year study of fish impingement rates at ONS, a similar study on a less frequent basis was adopted by Duke Power Company and approved by the Nuclear Regulatory Commission. The study consisted of quarterly inspections of the same six intake screens to monitor the seasonal rates of fish impingement at ONS. Except for threadfin shad, the numbers of impinged fish remained relatively low throughout the quarterly inspections in 1975 and 1976 (Table 8-3). Species composition was relatively constant, with threadfin shad, yellow perch, and bluegill being most commonly impinged. The average daily fish impingement rates for fish other than threadfin shad during the 7 day period preceding each quarterly inspection remained relatively constant except for a slight increase during the winter of 1975-1976 (Figure 8.2). However, as discussed in the bi-weekly inspections, impingement of threadfin shad is strictly seasonal. During the winters of 1975 and 1976, the rate of impingement of threadfin shad increased as the water temperature decreased (Figure 8-2), thus providing further verification that threadfin shad are susceptible to cold winter temperatures. Apparently, threadfin shad move into the intake canal during the winter months and become subjected to a continuous flow of water toward the intake structure. The temperature stress of the fish, in conjunction with the intake flow, results in their being impinged upon the intake screens.

ENTRAINMENT OF FISH EGGS AND LARVAE

The results of the bi-weekly (weekly in 1975 and 1976) monitoring of the ONS cooling water system for entrainment of fish eggs and larvae are presented in Table 8.4. Sample volumes during the major spawning period of Lake Keowee fishes ranged from 3.8 to 200.4 m^3. Sampling duration ranged from 0.4 to 24.6 hours. In 17 months of sampling, through four spawning seasons, only 1 fish larvae (threadfin shad) and no fish eggs were collected.

Sample volumes for each of the four 15 minute tows (two at the lake surface and two at a depth of five meters) along the main axis of the intake canal ranged from 428 m^3 to 1002 m^3 (Table 8-5). Sample volumes for the stationary net placed in the opening of the skimmer wall ranged from 101 m^3 to 743 m^3. No fish eggs or larvae were collected in 1975. During 1976 a total of five larval fish and three fish eggs was collected within or entering the intake canal. One black crappie and two threadfin shad larvae plus three threadfin shad eggs were collected while sampling with the stationary net placed in the opening of the skimmer wall. One threadfin shad and one yellow perch were collected during the surface tows. No fish eggs or larvae were collected by the tows at 5 meters (Table-5).

The placement of the skimmer wall across the entrance to the intake canal limits the passage of fish eggs and larvae to those occurring in the bottom of the lake near the opening in the skimmer wall. Semi-monthly sampling of fish eggs and larvae by SERI on the lake-side of the skimmer wall at a depth of 20.5 m show that few young fish occurred in this area (Addendum C). Thus few fish were entrained by the cooling water flow. SERI also found the smallest numbers of young fish near the heated discharge compared to other areas of the lake further indicating entrainment to be minimal.

GAS-BUBBLE DISEASE AND SUPERSATURATION OF DISSOLVED GASES

Fish which were collected in the discharge area of Lake Keowee and examined by SERI failed to show any evidence of GBD, although supersaturation of nitrogen was evident during most of the sampling periods (Table 8-6). The highest nitrogen saturation value recorded was 130.8% at location 501.0 in February 1974. The highest value recorded for the ONS discharge (location 530.9) was 110.1%. The highest oxygen saturation value recorded was 120.5% at location 501.0 in February 1974. The highest value recorded for the ONS discharge was 108.7% (Table 8-6). A plot of the mean and standard deviations of oxygen and nitrogen saturation values by sampling locations show a slight depression in saturation values in the intake canal followed by an increase at the discharge (Figure 8-3). However, a test for significant differences in the saturation values of both gases for the eight sampling locations failed to show a significant difference at $p = 0.05$.

A plot of the mean and standard deviations of oxygen and nitrogen saturation values (Figure 8-6 and 8-7, respectively) by sampling months show saturation values to peak generally during the month of February. A comparison of saturation values for the three winter periods for winter to winter variation failed to show a significant difference at $p = 0.05$.

IV. SUMMARY AND CONCLUSIONS

FISH POPULATION DYNAMICS

Fish Populations in Keowee Reservoir, South Carolina, Prior to Nuclear Power Generation, 1968-73 (Addendum A-1)

This report provides baseline information for assessing possible changes in the fish populations resulting from: 1) the operation on ONS, 2) environmental conditions as the reservoir underwent filling (1968-1970), and 3) aging of the lake prior to the addition of heat (1971 to 1973).

Seventeen of 40 species of fish reported from Lake Keowee from 1968 to 1973, were identified as being dependent on a tributary stream for spawning. Many of these species were not capable of making the transition from a stream environment to a reservoir environment and, thus, are present in low numbers or no longer occur in the lake.

Threadfin shad, white catfish, pumpkinseed, longear sunfish, spotted sunfish, and white crappie were collected only once during the 6 years prior to nuclear operations, while yellow bullhead and walleye were only collected twice. An attempt to stock walleye in 1970 failed.

Carp produced a large year class only during the first year of lake filling (1968). High survival rates of that year class accounts for the major component of the fish standing crop in subsequent years.

Species which produced year classes during the filling of the reservoir but low year classes since the lake completed filling include: chain pickerel, golden shiner and brown bullhead. In 1973 golden shiner and chain pickerel had already declined to low numbers while brown bullhead was beginning to decline.

Only 9 of the original 40 species reported for Lake Keowee prior to ONS operations (1973) produced significant year classes after the lake completed filling (April, 1971). These nine species were: whitefin shiner, flat bullhead, redbreast sunfish, green sunfish, warmouth, bluegill, largemouth bass, black crappie, and yellow perch. Seven of these nine species are reproducing successfully in 4 nearby reservoirs which indicates that these nine species should continue to maintain themselves in Lake Keowee.

<u>Prediction of Fish Biomass, Harvest and Prey-Predator Relations in Reservoirs (Addendum A-2)</u>

Estimates of the standing crop of fish in Lake Keowee declined from the second through the ninth year of impoundment. In the ninth year of impoundment the field estimate of the standing crop equaled the predicted standing crop (50 kg/ha). The predicted standing crop was based on a regression model of total standing crop versus total dissolved solids. Knowledge of trends in the standing crop of fish in new reservoirs coupled with predictive capabilities, such as the one above, prevents biased inferences from being made concerning the fish population dynamics of a reservoir and the possible environmental impact of man-induced stresses. For example, without the predictive capability above, one might easily attribute the decline in standing crop of fish in Lake Keowee to the operation of ONS.

A method to estimate prey-predator relationships in reservoirs was developed by Jenkins and Morais (in press) based on August cove rotenone samples. A plot of PREY/PRED calculations of thermally stressed Lake Keowee indicates prey biomass was inadequate in 1973 and 1974. In 1974 threadfin shad was stocked in the lake and in 1975 and 1976 prey biomass was more than adequate (Adequacy is based on a minimum desirable prey to predator biomass ratio of 1 to 1). Although the prey biomass was more than adequate in 1975 and 1976, the predator crops declined considerably.

Summary of Fish Population Data from Keowee Reservoir, 1972-1976 (Addendum A-3)

Seining

Littoral fishes decreased in abundance for the five seining locations combined during each year from 1973 through 1976. Whitefin shiner and bluegill sunfish were the most abundant species, respectively, in 1973, 1974 and 1975. In 1976, whitefin shiner and spottail shiner were the most abundant species, respectively. Spottail shiner, first collected in 1975, was the only species to increase in number. Most (>90%) of the spottail shiners were collected in the heated water discharge area of the lake both in 1975 and 1976. Juvenile largemouth bass were consistently collected at all sampling locations throughout the lake, however, they also declined in total numbers from 1973 to 1975. In 1975 and 1976 the total numbers of largemouth bass collected were approximately equal. With the exception of 1973, the only sampling location to show an increase in total numbers of fishes collected and percent of total seine catch was the heated water discharge area. This was due primarily to an increase in catch of spottail shiners.

Gill Netting

The total numbers of fishes collected by gill netting (three sampling locations combined) has decreased yearly from 1430 fish in 1972-1973 to 864 fish in 1976-1977. Two of the three sampling locations (pumpback area and southern portion of the lake) showed a consistent decrease in total numbers of fish for each year, 1972-1977. However the third sampling location (heated water discharge) after a yearly decline from 1972 to 1974, showed a yearly increase in total numbers of fish collected during the 3 year period 1974 to 1977.

The species most frequently collected in decreasing order of abundance were: flat bullhead, silver redhorse, carp, black crappie, quillback, bluegill, largemouth bass and yellow perch. Three of the 11 species collected during the first year (1972-1973) disappeared by the fifth year (1976-1977), these species were: chain pickerel, golden shiner and bluegill. Largemouth bass (except 1976-77), black crappie and flat bullhead were the only three species that increased in relative abundance from 1972 to 1977.

Rotenoning

Total mean standing crop of all fish collected during rotenone sampling of three coves in Lake Keowee for the five year period, 1972 through 1976 were: 98.3 kg/ha in 1972, 44.7 kg/ha in 1973, 79.5 kg/ha in 1974, 56.7 kg/ha in 1975, and 49.1 kg/ha in 1976. With the exception of 1974, the highest total standing crop was recorded for the Crow Creek area, followed by the area near the skimmer wall and then Cane Creek.

Carp accounted for 43-68% of the total standing crop each year, even though 1968 was the last year of successful spawning of carp (Addendum A-1). Largemouth bass, black crappie and bluegill sunfish, three of the most important game species in the lake, showed slight increases in standing crop during the period 1972-1974. Since 1974 (1974-1976), the standing crop of each species has declined. The decrease in the standing crop of largemouth bass and black crappie in 1975 and 1976 (which is contrary to the gill netting results) may be due to the movement of these two species from the coves to the cool deeper water in the lake during the time of rotenone sampling (August). Threadfin shad, stocked in 1974 by the S. C. Wildlife and Marine Resources Department, appears to be well established in the lake as it accounted for 12.5% of the standing crop in 1975 and 6.9% in 1976.

Population Dynamics of Young-of-the Year Fish in a Reservoir Receiving Heated Effluent (Addendum A-4)

Water temperatures, taken in conjunction with trawling samples during the period 1973-1976 showed the effects of added thermal input. First, the lake warmed earlier causing a shift in the beginning of spawning to a period earlier in the year (black crappie more so, than for any other species). The length of young fish at first capture remained the same in all years, but the young were captured 44 days earlier in 1976 than in 1973. Second, warm water extended to greater depths during the operation of ONS compared to the years preceding operation resulting in a deeper, poorly-defined thermocline throughout the summer. For example, the water temperature at 6 m during the summer of 1975 at the South station was 2.1 to 6.2 C^{o} warmer than in 1973.

Numbers of young-of-the-year fish captured declined from 1973 to 1976. Yellow perch declined from a combined mean (1 and 5.5 m composite for all stations) of 19.2 fish/haul (8891 fish) in 1973 to 0.5 fish/haul (233 fish) in 1976. Black crappie declined from a combined mean of 4.3 fish/haul (1480 fish) in 1973 to 1.7 fish/haul (756 fish) in 1976. Threadfin shad, not present in 1973, showed a slight increase in a combined mean of 1.6 fish/haul (735 fish) in 1974 to 1.9 fish/haul (842 fish) in 1976. Sunfish experienced the largest decline, a combined mean decrease from 21.5 fish/haul (9963 fish) in 1973 to 0.2 fish/haul (89 fish) in 1976. Even though warm water extended to a greater depth during the summers of 1974-1976 as compared to 1973, catches at both 1 and 5.5 m depths declined for yellow perch, sunfishes and black crappie.

Of the four stations sampled, the discharge area showed the largest decline of young fish from 1973 to 1976. A possible explanation of this could be an increase in large amounts of relatively fish-free water discharged from ONS. Sampling conducted within the station and in the intake canal by Duke Power biologists showed very low numbers of larval fish entrained in the CCW system and present in the intake canal (Duke Power Company 1975a, b, 1976). Sampling conducted on the lakeside of the skimmer wall at the depth of 20.5 m, which corresponds to the depth of the opening in the skimmer wall, showed very low numbers of larval fish present which might be subject to entrainment in the ONS condenser cooling water.

The decline in the number of young-of-the-year appeared to be related to the alteration of the thermal regime and changes in the fish population due to aging of the reservior. The increased thermal input may have been sufficient to alter the reproductive or behavioral patterns of fish, resulting in a decline in the numbers of larval fish present in the open water of the lake.

Life History Studies Reports and Assembled Data (Addendum A-5)

Food Habits of Young-of-the Year Black Crappie

Food habits of larval and juvenile black crappie in Lake Keowee were similar to published studies of reservoirs without thermal inputs. Principal food organisms consumed by larval fish were *Diaphanosoma* sp. and copepod nauplii. Principal food organisms consumed by juveniles were *Diaphanosoma* sp., *Diaptomus* sp., and *Mesocyclops* sp.

The food habits of both larval and juvenile black crappie during the operation of ONS (1976) were similar to the pre-operational food habits (1973). The abundance of food organisms in the discharge area were not seriously affected by the operation of ONS, since the food habits of juvenile and larval black crappie were similar for both the control and outfall areas in 1973 and 1976.

Largemouth Bass Growth in Keowee Reservoir

The growth rate of young-of-the-year largemouth bass was greatest in 1973 and least in 1976, while the growth rate in 1972, 1974, and 1975 were similar. The growth rate of adult (age 1 year and older) largemouth bass was greater during the filling of the reservoir than after the reservoir filled. The growth rate of Lake Keowee largemouth bass was less than the growth rates of largemouth bass from reservoirs at similar latitudes. The reason for the slow growth rate may have been due to the low abundance of prey species during the first few years after the reservoir completed filling.

Creel Census in Reservoirs (Addendum A-7)

Lake Keowee had an annual average fishing pressure of 8.86 hrs/acre in 1971, 9.22 hrs/acre in 1972, 3.64 hrs/acre in 1973, 3.26 hrs/acre in 1974, and 3.21 hrs/acre in 1975. There was also a steady decline in both the mean weight and numbers of fish harvested per surface acre: 8.86 fish weighing 3.99 lbs. in 1971; 9.86 fish weighing 6.00 lbs. in 1972; 3.20 fish weighing 1.86 lbs. in 1973; 2.21 fish weighing 1.70 lbs. in 1974; and 1.79 fish weighing 1.38 lbs. in 1975.

Bluegill followed by crappies and largemouth bass were the dominant species (number) in the creels. Largemouth bass, crappies and bluegill, respectively, were the dominant species in the creels with respect to weight.

A comparison of creel data for various areas of Lake Keowee showed little difference in the total catch. Fishing success was greatest in the heated water area for both black crappie and bluegill sunfish, especially in the winter.

S. C. Wildlife and Marine Resources Department concluded that the fish populations in Keowee Reservoir could withstand considerably more angling pressure without harm to the present fishery resource.

FISH IMPINGEMENT ON INTAKE SCREENS

Results of the two quantitative studies, bi-weekly and quarterly inspections of 6 representative intake screens, showed that low numbers of fish (usually yellow perch and bluegill less than 10 cm in length), were impinged on the intake screens during the spring, summer, and fall seasons. During the winters of 1974-76, threadfin shad, a species introduced into Lake Keowee in January and February 1974, was the species most commonly impinged. Large numbers of threadfin shad move to the area of the skimmer wall during the winter months and as they swim under the skimmer wall they are subjected to a continuous flow (approximately 30.48 cm/sec in the middle of the intake canal with all CCW pumps operating) toward the intake structure. In addition, threadfin shad are susceptible to cold winter water temperatures and may undergo a complete die-off during a sufficiently cold winter. Large numbers of the threadfin shad which are subjected to cold water temperatures and continuous flow, eventually become impinged upon the intake screens. The loss of fish impinged on the intake screens, primarily threadfin shad, during the period June 1973 to December 1976 was not considered to be detrimental to the fishery resource of Lake Keowee.

ENTRAINMENT OF FISH EGGS AND LARVAE

The collection of one larval fish and no eggs in four years of sampling within the condenser cooling water system clearly shows entrainment of fish eggs and larvae at Oconee Nuclear Station to be minimal. Based upon supplemental sampling of the water flowing into the intake canal, it is apparent that the skimmer wall limits the entrainment of fish eggs and larvae to those organisms which occur at a depth in the lake at or near the opening in the skimmer wall. It is also apparent that based upon the small numbers of fish eggs and larvae collected during sampling within the intake canal that reproduction of fish inhabiting the intake canal is minimal or non-existent. Therefore, the entrainment of fish eggs and larvae caused by the operation of Oconee Nuclear Station has not had a measurable impact upon the fishery resource of Lake Keowee.

GAS-BUBBLE DISEASE AND SUPERSATURATION OF DISSOLVED GASES

No evidence of GBD in Lake Keowee fishes has been discovered by biologist from SERI even though supersaturation of both nitrogen and oxygen was evident in the lake. Evidence of supersaturation of these two gases has been documented both near and distant to the discharge area of ONS. Percent saturation values were generally depressed in the intake canal and elevated at the discharge and Location 508.0. However, a test for a significant difference in saturation values for the eight sampling stations failed to show a significant difference. An analyses of saturation values for the three winter sampling periods (1974-76) also failed to show a significant difference.

The absence of symptoms of GBD in Lake Keowee fishes in the area of the discharge may indicate that fish do not remain in the warm water discharge long enough to develop the disease and/or that the concentrations of these two gases are not high enough to result in the symptoms of GBD. The presence of supersaturated gases in waters distant from the discharge suggests the latter.

V. RECOMMENDATIONS

1. Since the studies of fish impingement on ONS intake screens have documented the seasonal and annual patterns of impingement, and since the loss of fish due to impingement was concluded to have no significant impact on the fisheries resource of Lake Keowee, we recommend eliminating all requirements for monitoring and reporting fish impingement at ONS (Specification 1.4 A).

2. Since entrainment of fish eggs and larvae through the ONS cooling water system was concluded to have no measurable effect on the fisheries resource of Lake Keowee, we recommend eliminating all requirements for monitoring and reporting entrainment of fish eggs and larvae (Specification 1.4 B).

3. Since Gas Bubble Disease (GBD) in fishes of Lake Keowee has never been detected, we recommend eliminating all requirements for monitoring and reporting (a) fish with symptoms of GBD (Specification 1.7 A) and (b) dissolved nitrogen and oxygen gases in Lake Keowee (Specification 1.7 B).

4. The studies of species composition and general distribution of fish in Lake Keowee indicate no adverse effects resulted from the operation of ONS. While the abundance of many species has changed during the study period, changes caused by ONS could not be distinguished from those predicted to occur naturally. The rather steady decline of fish abundance from 1969 through 1976 is not unusual for a new reservoir, and the standing crop obtained in 1976 was very close to that predicted solely on the basis of Lake Keowee's dissolved solids concentration.

   Since it is not apparent, however, whether the standing crop of fishes in Lake Keowee has stabilized, it is recommended that the cove rotenone sampling (part of Specification 1.3.2 A) be continued until the objectives of the specification are more fully met.

   It is recommended that all other sampling requirements in Specifications 1.3.2 A and 1.3.2 B be eliminated.

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Table 8-1. Monthly summaries of fish observed from the intake structure during the weekly visual inspections, June 1973 to April 1976.

DATE	NO. FISH OBSERVED	SPECIES COMPOSITION				SIZE GROUPS (cm)				
		BG	YP	TS	M	2-4	4-6	6-8	8-10	10+
6/73	0	0	0	0	0	0	0	0	0	0
7/73	0	0	0	0	0	0	0	0	0	0
8/73	0	0	0	0	0	0	0	0	0	0
9/73	0	0	0	0	0	0	0	0	0	0
10/73	0	0	0	0	0	0	0	0	0	0
11/73	0	0	0	0	0	0	0	0	0	0
12/73	0	0	0	0	0	0	0	0	0	0
1973 Total	0	0	0	0	0	0	0	0	0	0
1/74	0	0	0	0	0	0	0	0	0	0
2/74	1	0	1	0	0	0	0	0	1	0
3/74	7	0	2	0	5	0	0	6	1	0
4/74	1	1	0	0	0	0	0	1	0	0
5/74	0	0	0	0	0	0	0	0	0	0
6/74	0	0	0	0	0	0	0	0	0	0
7/74	5	3	0	0	2	0	0	3	0	2
8/74	7	3	1	0	3	2	1	0	2	2
9/74	0	0	0	0	0	0	0	0	0	0
10/74	0	0	0	0	0	0	0	0	0	0
11/74	1	0	0	0	1	0	0	0	0	1
12/74	0	0	0	0	0	0	0	0	0	0
1974 Total	22	7	4	0	11	2	1	10	4	5

Species Composition - BG - Bluegill, YP - Yellow Perch, TS - Threadfin Shad, M - Miscellaneous

Table 8-1 (Cont.). Monthly summaries of fish observed from the intake structure during the weekly visual inspections, June 1973 to April 1976.

DATE	NO. FISH OBSERVED	SPECIES COMPOSITION				SIZE GROUPS (cm)				
		BG	YP	TS	M	2-4	4-6	6-8	8-10	10+
1/75	15	0	0	15	0	3	10	2	0	0
2/75	67	1	0	66	0	8	48	11	0	0
3/75	12	1	0	11	0	2	4	6	0	0
4/75	3	1	0	2	0	0	1	1	1	1
5/75	0	0	0	0	0	0	0	0	0	0
6/75	0	0	0	0	0	0	0	0	0	0
7/75	3	0	1	2	0	1	1	0	1	0
8/75	5	5	0	0	0	0	5	0	0	0
9/75	4	2	2	0	0	0	2	2	0	0
10/75	8	0	2	6	0	5	0	3	0	0
11/75	0	0	0	0	0	0	0	0	0	0
12/75	1	0	0	1	0	0	1	0	0	0
1975 Total	118	10	5	103	0	19	72	25	2	0
1/76	103	0	0	103	0	0	98	5	0	0
2/76	36	0	0	36	0	0	31	5	0	0
3/76	4	0	0	4	0	0	4	0	0	0
4/76	0	0	0	0	0	0	0	0	0	0
1976 Total	143	0	0	143	0	0	133	10	0	0

Table 8-2. Summary of fish impingement as determined by quarterly screen inspections with SCUBA, June, 1973 to March, 1976.

DATE	NO. SCREENS INSPECTED	NO. FISH IMPINGED	SPECIES COMPOSITION						SIZE GROUPS (cm)				
			BG	YP	LMB	TS	U	M	2-4	4-6	6-8	8-10	10+
6/28/73	6	7	1	1	2	0	1	2	0	1	2	0	4
8/29/73	8	277	15	260	0	0	0	2	-	-	-	-	-
12/05/73	10	186	172	13	0	0	0	1	0	186	0	0	0
73 Total	24	470	188	274	2	0	1	5	0	187	2	0	4
3/28/74	6	3830	1732	646	0	0	1451	1	0	3183	646	0	1
6/07/74	12	1529	1111	206	8	0	201	3	0	1110	409	0	10
9/16/74	24	235	127	40	1	3	55	9	134	57	14	11	19
12/11/74	6	631	27	153	0	318	132	1	377	201	43	2	8
74 Total	48	6225	2997	1045	9	321	1839	14	511	4551	1112	13	38
3/12/75	6	5747	6	183	1	5068	489	0	820	2798	1323	738	68
6/19/75	6	1500	487	353	0	68	592	0	516	873	97	6	8
9/24/75	6	3433	0	3	0	3393	37	0	1	2658	494	278	2
12/30/75	6	16531	0	1	0	16530	0	0	0	12474	3715	342	0
75 Total	24	27211	493	540	1	25059	1118	0	1337	18803	5629	1364	78
3/30/76	6	9939	0	913	0	4014	5010	2	2105	6918	912	3	1
76 Total	6	9939	0	913	0	4014	5010	2	2105	6918	912	3	1

Dash (-) indicates no data recorded

Species Composition - BG- Bluegill,YP-Yellow Perch, LMB-Largemouth Bass, TS-Threadfin Shad, U-Unidentifiable, M-Miscellaneous.

Table 8-3. Summary of fish impingement by screen inspection date August, 1973 to October, 1976.

	DATE	NO SCREENS	WFI (kg)	NFI #	SPECIES COMPOSITION BG	YP	TS	U	M	SIZE GROUPS (cm) 2-4	4-6	6-8	8-10	10+
-	08/09/73	2	0.84	38	10	21	0	2	5	1	14	22	0	1
	TOTAL	2	0.84	38	10	21	0	2	5	1	14	22	0	1
-	01/29/74	2	3.68	1674	34	277	1	1360	2	0	1393	182	97	2
-	02/09/74	2	0.60	271	1	197	0	73	0	0	271	0	0	0
+	05/16/74	6	0.20	95	45	48	0	0	2	23	33	34	3	2
+	05/30/74	6	1.96	891	432	448	0	2	9	128	725	26	11	1
+	06/13/74	6	0.13	61	47	14	0	0	0	10	37	14	0	0
+	06/27/74	6	1.12	965	639	240	0	79	7	554	299	103	7	2
+	07/11/74	6	11.21	3481	1373	201	0	1901	6	708	2620	132	10	11
+	07/25/74	6	3.62	1112	266	115	0	722	9	197	813	90	4	8
+	08/08/74	6	2.15	838	336	106	0	393	3	290	474	69	0	5
+	08/22/74	6	6.65	2935	732	327	0	1874	2	621	1915	364	21	14
+	09/05/74	6	0.25	132	21	7	0	100	4	88	26	14	2	2
+	09/19/74	6	0.02	17	1	1	0	15	0	9	2	2	3	1
+	10/03/74	6	0.12	81	23	18	0	39	1	54	19	6	1	1
+	10/17/74	6	0.12	144	17	28	2	93	4	63	64	12	4	1
+	10/31/74	6	0.10	92	2	0	0	90	0	10	61	20	0	1

- Results of non-scheduled screen inspections
+ Results of bi-weekly inspections of 6 representative intake screens (14 day accumulation period).
* Results of quarterly screen inspections of 6 representative intake screens (1 week accumulation period).
WFI-Weight of fish impinged
NFI-Number of fish impinged
Species Composition- BG- Bluegill, YP- Yellow perch, TS- Threadfin shad, U- unidentifiable, M- Miscellaneous

Table 8-3 (cont.). Summary of fish impingement by screen inspection date, August, 1973 to December, 1976.

	DATE	NO SCREENS	WFI (kg)	NFI #	SPECIES COMPOSITION BG	YP	TS	U	M	SIZE GROUPS (cm) 2-4	4-6	6-8	8-10	10+
-	11/04/74	4	0.07	69	3	6	2	57	1	18	43	5	2	1
-	11/06/74	7	0.06	48	14	5	24	2	3	30	10	8	0	0
-	11/07/74	5	0.07	59	15	13	23	3	5	25	17	15	2	0
-	11/08/74	3	0.01	3	1	2	0	0	0	1	1	1	0	0
+	11/21/74	6	1.15	685	76	60	273	272	4	375	235	62	3	10
+	12/05/74	6	1.50	695	101	38	154	395	7	117	475	89	10	4
+	12/19/74	6	12.90	8602	30	42	6497	2032	1	2428	5425	745	2	2
-	12/19/74	4	1.25	1708	1	3	1615	89	0	451	1221	36	0	0
	TOTAL	119	53.04	26108	4211	2201	9950	9676	70	6118	17652	2088	182	68
+	01/02/75	6	3.20	2168	2	12	1824	330	0	681	1254	233	0	0
+	01/16/75	6	10.46	5086	41	120	4326	597	2	1538	3008	529	6	5
+	01/30/75	6	3.35	1404	1	16	1303	84	0	306	817	281	0	0
+	02/13/75	6	102.10	42543	4	302	26664	15571	2	11740	25759	4820	224	0
-	02/13/75	2	122.38	50994	0	4	26465	24545	0	9800	28400	12794	0	0
+	02/27/75	6	89.26	37192	21	1437	31135	4597	2	8964	22925	4816	485	2
-	02/27/75	3	72.28	30115	0	0	96	30019	0	11520	13735	4394	466	0
-	03/04/75	3	43.00	24350	0	0	0	24350	0	9500	12250	2600	0	0
+	03/14/75	6	66.03	29989	4	861	12453	16669	2	7645	19214	2905	225	0
+	03/28/75	6	21.92	8869	168	806	2856	5037	2	3790	3313	1651	114	1
-	03/28/75	2	10.71	4463	149	688	997	2627	2	1875	1919	556	110	3
+	04/10/75	6	15.20	6136	77	849	1339	3868	3	1845	3126	1152	10	3
+	04/24/75	6	6.37	1217	5	25	87	1097	3	220	612	374	11	0
+	05/09/75	6	0.06	26	0	0	0	25	1	1	21	2	0	2
-	08/07/75	6	3.52	1785	3	55	42	1685	0	3	988	785	9	0
*	08/14/75	6	0.80	350	26	61	4	259	0	51	182	115	2	0
-	09/12/75	2	0.02	12	1	7	4	0	0	12	0	0	0	0
-	09/25/75	2	0.22	88	0	0	0	88	0	0	32	55	0	1
-	10/20/75	2	0.21	68	3	0	0	65	0	0	68	0	0	0
-	11/04/75	8	0.71	353	3	0	10	340	0	0	303	47	1	2

Table 8-3 (cont.). Summary of fish impingement by screen inspection date, August, 1973 to December, 1976.

	DATE	NO SCREENS	WFI (kg)	NFI #	SPECIES COMPOSITION BG	YP	TS	U	M	SIZE GROUPS (cm) 2-4	4-6	6-8	8-10	10+
-	11/05/75	4	0.25	66	1	0	0	65	0	0	23	42	0	1
*	11/11/75	6	0.11	65	0	2	19	43	1	1	28	30	5	1
-	12/22/75	2	6.19	2133	1	2	1265	865	0	1165	968	0	0	0
-	12/29/75	4	12.10	4825	0	0	1625	3200	0	1045	3780	0	0	0
	TOTAL	112	589.45	253547	485	5177	112260	135603	22	71356	143103	37426	1633	20
-	01/09/76	8	13.60	5343	0	48	1210	4085	0	125	4507	711	0	0
-	01/14/76	8	54.86	20860	0	0	6975	13885	0	0	19635	1225	0	0
-	01/16/76	4	17.56	7005	0	25	6980	0	0	0	5585	1420	0	0
-	01/20/76	4	109.71	43237	14	47	16176	27000	0	22550	19397	1177	112	1
-	01/30/76	2	33.13	13250	0	0	9050	4200	0	0	11000	2250	0	0
-	02/12/76	6	18.60	7037	0	292	3695	3050	0	0	5750	1287	0	0
*	02/19/76	6	23.78	6547	5	480	4885	1177	0	1562	3185	1795	5	0
-	05/03/76	4	0.04	12	1	10	1	0	0	0	2	10	0	0
-	05/19/76	4	0.64	245	0	245	0	0	0	0	0	245	0	0
-	06/05/76	8	9.20	3170	25	505	260	2380	0	0	2665	505	0	0
-	06/06/76	8	13.90	4940	15	795	345	3785	0	0	825	4115	0	0
-	06/18/76	6	4.10	1129	16	150	50	910	3	0	121	1005	0	3
*	06/25/76	6	5.32	739	128	58	0	553	0	0	427	311	0	1
-	09/10/76	6	0.47	192	0	0	19	173	0	19	173	0	0	0
*	09/17/76	6	0.34	71	17	0	2	52	0	1	69	0	0	1
-	11/12/76	6	4.94	1647	15	27	1605	0	0	1400	240	7	0	0
-	11/18/76	8	2.51	852	0	0	467	385	0	672	180	0	0	0
-	12/02/76	8	7.23	2588	0	0	983	1605	0	0	2588	0	0	0
*	12/08/76	6	10.81	3614	2	31	3551	30	0	0	3582	2	30	0
-	12/29/76	8	15.87	6985	0	0	3535	3450	0	0	6965	20	0	0
-	12/30/76	4	11.52	4826	0	1	3450	1375	0	0	4825	1	0	0
	TOTAL	126	358.13	134289	238	2714	63293	68095	3	26329	91721	16086	147	6

Table 8-4. Monthly summaries of entrainment of fish eggs and larvae within the ONS Condenser Cooling Water System, May, 1973 to August, 1976.

DATE	AVG DURATION HOURS	AVG INTAKE TEMP °C	AVG DISCHARGE TEMP °C	AVG SAMPLE VOLUME (m^3)	AVG FLOW (m^3/MIN)	NO. FISH EGGS ENTRAINED	NO. FISH LARVAE ENTRAINED
5/73	0.8	-	-	3.79	0.08	0	0
6/73	0.4	11.0	13.9	3.79	0.16	0	0
7/73	0.5	11.2	11.8	3.79	0.13	0	0
4/74	0.5	12.1	18.8	5.05	0.16	0	0
5/74	0.5	14.1	13.7	5.68	0.18	0	0
6/74	0.5	15.6	23.7	3.79	0.18	0	0
7/74	0.6	18.3	28.8	4.69	0.17	0	0
4/75	11.8	11.3	18.4	69.77	0.10	0	0
5/75	24.2	13.0	22.9	157.10	0.11	0	0
6/75	24.0	16.0	26.4	160.92	0.11	0	0
7/75	23.3	19.5	28.8	153.80	0.11	0	0
3/76	24.2	10.4	10.7	132.86	0.09	0	0
4/76	24.6	12.3	14.9	127.25	0.09	0	0
5/76	23.8	13.8	13.9	131.30	0.09	0	0
6/76	24.6	16.1	26.7	146.74	0.10	0	0
7/76	24.6	18.7	28.7	154.05	0.10	0	0
8/76	24.1	22.2	30.6	168.96	0.12	0	1

Threadfin shad (p382)

- Temperatures not recorded

Average discharge and intake temperatures taken from the sampling dates in the respective month

Table 8-5. Monthly summaries of sampling for fish eggs and larvae in the intake canal, 1975-1976.

DATE	SURFACE HAULS Volume (m^3)	SURFACE HAULS # Eggs	SURFACE HAULS # Larvae	5 METER HAULS Volume (m^3)	5 METER HAULS # Eggs	5 METER HAULS # Larvae	SKIMMER WALL Volume (m^3)	SKIMMER WALL # Eggs	SKIMMER WALL # Larvae
05/75	762.1	0	0	572.3	0	0	117.1	0	0
06/75	679.0	0	0	594.1	0	0	108.5	0	0
07/75	678.8	0	0	575.5	0	0	185.4	0	0
03/76	801.1	0	0	578.1	0	0	118.9	0	0
04/76	705.5	0	0	657.6	0	0	190.0	0	0
05/76	770.0	0	0	652.9	0	0	133.9	0	1
06/76	650.8	0	2	549.7	0	0	145.3	3	1
07/76	777.8	0	0	723.7	0	0	299.4	0	0
08/76	669.1	0	0	726.7	0	0	166.2	0	1

Table 8-6. Mean monthly dissolved gas saturation values[1] for Lake Keowee by sampling location, 1973-1976.

SAMPLING STATIONS

Date	501.0			502.0			Intake			Discharge			508.0			503.0			504.0			505.0		
	Temp (°C)	% Sat. O_2	% Sat. N_2	Temp (°C)	% Sat. O_2	% Sat. N_2	Temp (°C)	% Sat. O_2	% Sat. N_2	Temp (°C)	% Sat. O_2	% Sat. N_2	Temp (°C)	% Sat. O_2	% Sat. N_2	Temp (°C)	% Sat. O_2	% Sat. N_2	(°C)	% Sat. O_2	% Sat. N_2	Temp (°C)	% Sat. O_2	% Sat. N_2
11/15/73	17.2	75.2	87.3	17.9	71.2	83.6	18.0	55.2	66.9	25.0	62.4	74.9	20.1	79.8	101.0	19.0	57.3	71.4	20.0	60.4	74.5	18.9	83.3	102.9
12/20/73	12.9	63.3	74.2	12.9	73.1	83.0	13.2	69.7	74.7	18.0	72.3	83.8	16.3	68.4	80.3	15.0	75.6	86.3	15.4	80.9	90.0	13.6	77.1	87.9
01/23/74	12.3	113.1	115.2	12.4	100.1	102.9	12.3	82.1	90.5	13.0	80.6	90.5	12.5	81.1	90.6	12.8	98.4	105.2	13.0	85.7	94.2	13.3	96.5	99.7
02/18/74	10.7	120.5	130.8	11.2	113.3	125.2	11.1	89.4	99.5	17.7	98.6	110.1	13.3	92.7	105.0	11.9	107.7	116.8	13.0	95.7	105.8	12.2	91.5	101.9
03/20/74	14.2	104.6	108.8	14.2	95.0	101.6	11.9	83.7	98.4	14.9	87.0	101.3	13.7	86.2	99.4	14.2	94.7	100.1	14.4	89.5	102.3	14.2	91.9	100.5
04/24/74	17.4	111.0	110.7	17.6	100.5	102.9	14.2	83.8	97.6	17.7	91.2	105.8	17.4	97.8	109.6	17.3	98.5	105.8	17.6	98.8	104.8	17.5	101.4	96.3
11/28/74	15.2	62.3	87.6	15.7	56.0	70.8	16.0	87.1	97.7	21.6	96.8	109.6	19.3	93.0	108.2	17.2	47.0	64.8	18.7	86.2	100.2	17.5	86.1	98.5
12/26/74	11.4	84.4	91.0	12.4	85.4	95.2	11.4	83.0	93.5	17.6	87.8	98.2	14.1	91.5	102.8	12.9	84.7	90.8	14.2	88.0	106.4	13.7	86.5	91.4
01/31/75	11.6	106.5	108.7	12.6	98.8	100.2	11.1	94.7	104.4	16.2	104.9	113.1	13.9	79.4	82.4	12.1	89.1	87.0	14.2	81.0	78.1	13.3	80.7	87.8
02/27/75	10.5	94.9	97.0	10.8	96.4	104.0	10.4	85.1	95.6	14.6	91.5	104.1	12.0	75.4	78.2	10.9	92.4	103.7	12.3	92.4	98.1	11.5	83.6	81.2
03/19/75	10.3	89.2	87.1	11.7	89.1	87.2	10.9	93.6	92.1	19.8	108.7	109.2	15.6	94.7	93.9	13.5	89.6	88.6	15.1	91.7	90.8	12.4	89.5	90.3
04/23/75	16.6	80.1	76.5	17.2	85.5	86.2	12.8	84.9	96.0	16.7	92.8	104.8	16.3	83.3	95.1	16.9	88.9	96.2	16.3	89.0	99.9	17.3	92.8	97.5
11/04/75	20.8	73.5	87.9	21.3	74.4	89.2	21.1	71.4	87.3	28.5	79.2	95.5	25.0	80.8	97.2	22.9	74.0	88.6	24.2	80.3	97.0	23.4	80.9	94.3
12/05/75	15.7	81.0	98.6	17.2	78.3	93.0	16.4	88.3	95.2	22.7	92.0	102.1	21.4	82.3	88.7	18.7	91.0	98.5	19.8	83.7	92.6	19.4	88.4	94.7
01/07/76	10.6	87.9	93.8	12.3	93.2	95.8	11.6	82.8	96.0	18.3	92.8	102.0	16.5	99.3	105.9	14.6	91.8	95.7	16.2	91.5	88.2	15.4	96.8	94.5
02/20/76	11.8	98.7	101.4	13.0	96.6	100.4	10.0	87.6	97.6	14.2	97.2	105.4	13.8	98.1	105.6	12.6	90.7	96.7	13.6	95.9	102.5	13.9	99.0	100.4
03/04/76	15.9	100.5	98.7	15.7	98.0	99.2	10.7	79.4	92.1	16.3	92.1	104.7	14.9	95.3	104.8	14.4	93.6	98.3	14.2	91.2	97.6	14.3	84.2	89.3
04/01/76	14.7	92.9	94.4	15.2	92.0	99.5	12.0	76.8	75.7	14.5	80.3	99.1	14.4	87.9	102.9	15.3	86.8	101.9	14.6	91.9	101.4	15.3	96.6	100.4
11/11/76	16.3	85.1	96.7	17.0	87.6	95.5	16.5	85.0	97.2	20.0	93.7	99.7	19.3	90.2	102.1	17.7	81.2	101.0	18.7	87.0	98.6	17.9	94.5	110.2
12/16/76	11.4	84.9	91.5	12.7	85.7	91.3	11.9	91.3	97.7	18.0	97.7	103.5	15.3	94.0	100.0	13.4	90.4	92.6	15.1	91.7	96.9	13.5	90.6	94.3

[1] Average values for 4 sampling depths (0.3, 1.5, 3.0, and 6.1m).

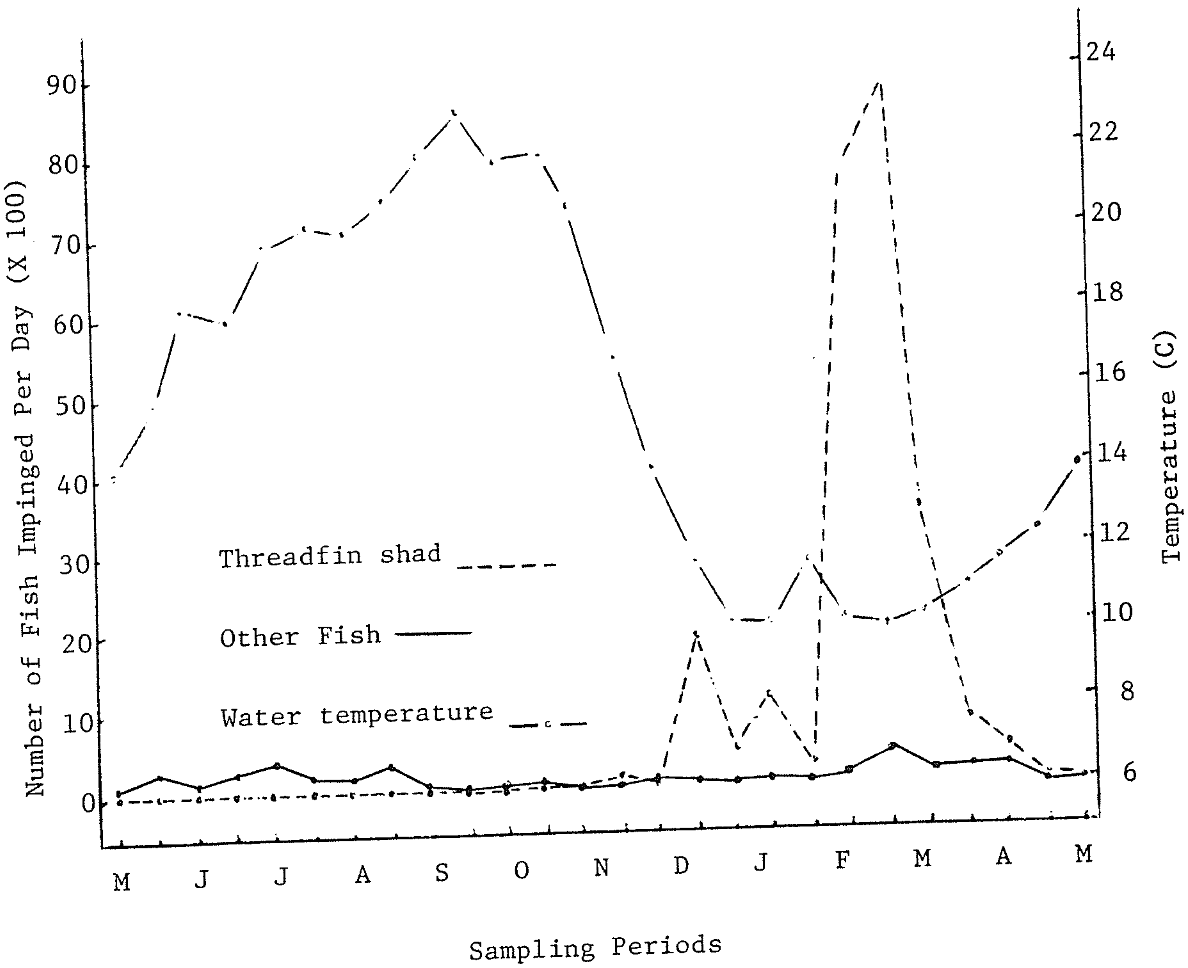

Figure 8-1. Daily fish impingement rates for ONS determined by the bi-weekly inspection of six representative intake screens (values were computed by multiplying the total of the screen inspections by four to obtain a station total and then dividing by fourteen, the number of days in the inspection period), May, 1974 to May, 1975.

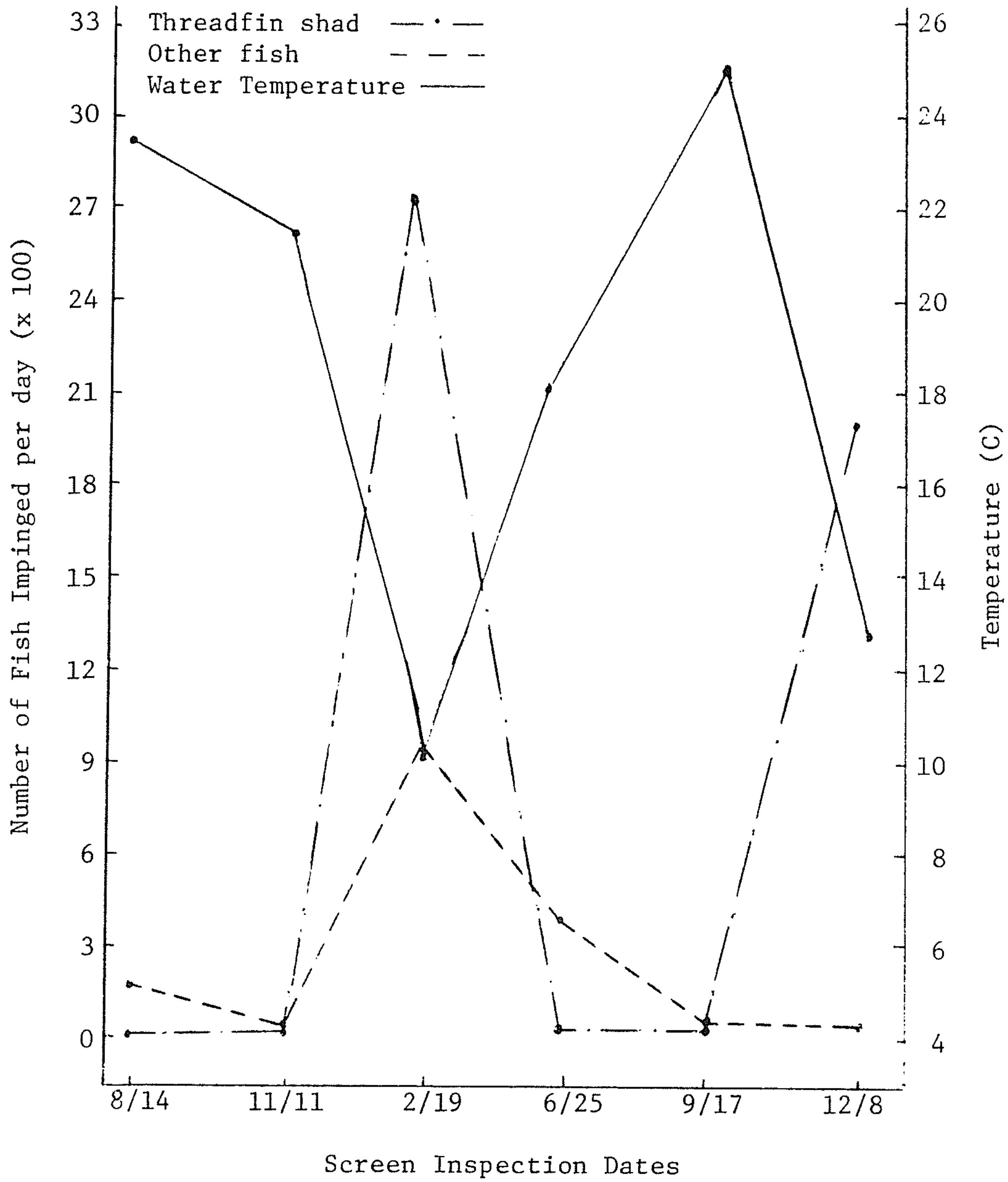

Figure 8-2. Seasonal fish impingement rates as determined by the quarterly screen inspections. (values were computed by multiplying the totals of the screen inspections by four for a station total and then dividing by seven, the number of days in the inspection period August, 1975 to December, 1976.

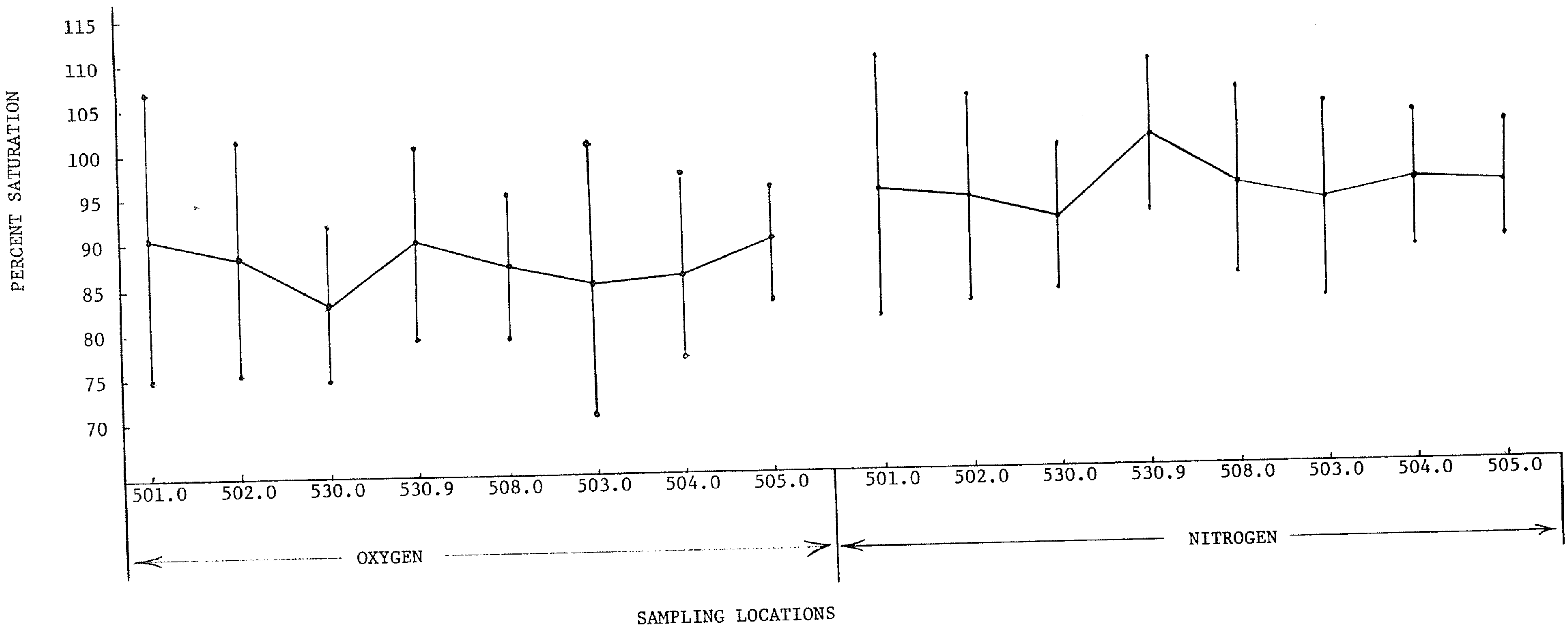

Figure 8-3. Mean and standard deviations of percent saturation values for oxygen values for oxygen and nitrogen by sampling locations, 1973-1976.

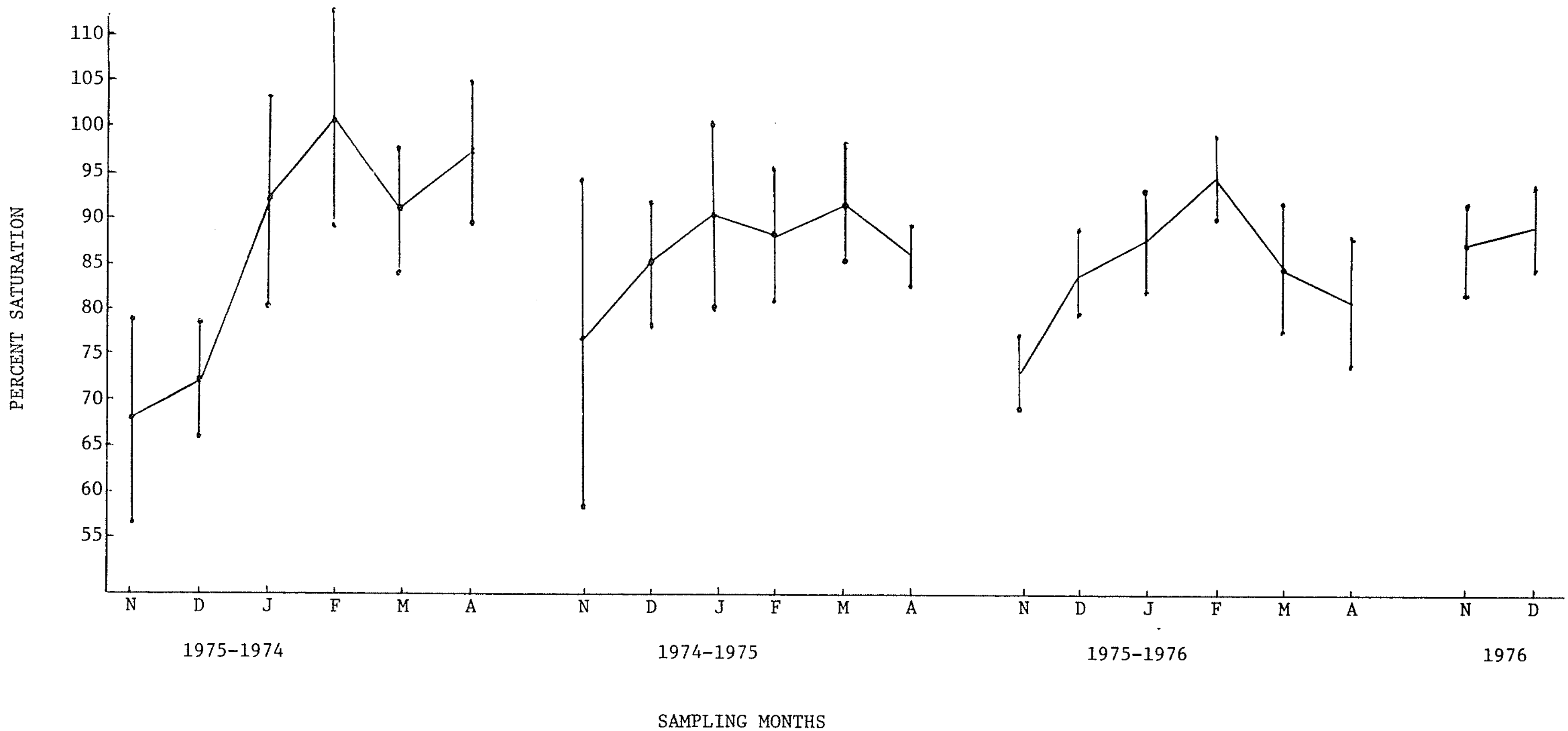

Figure 8-4. Mean and standard deviations of percent saturation values for oxygen by sampling month, 1973-1976.

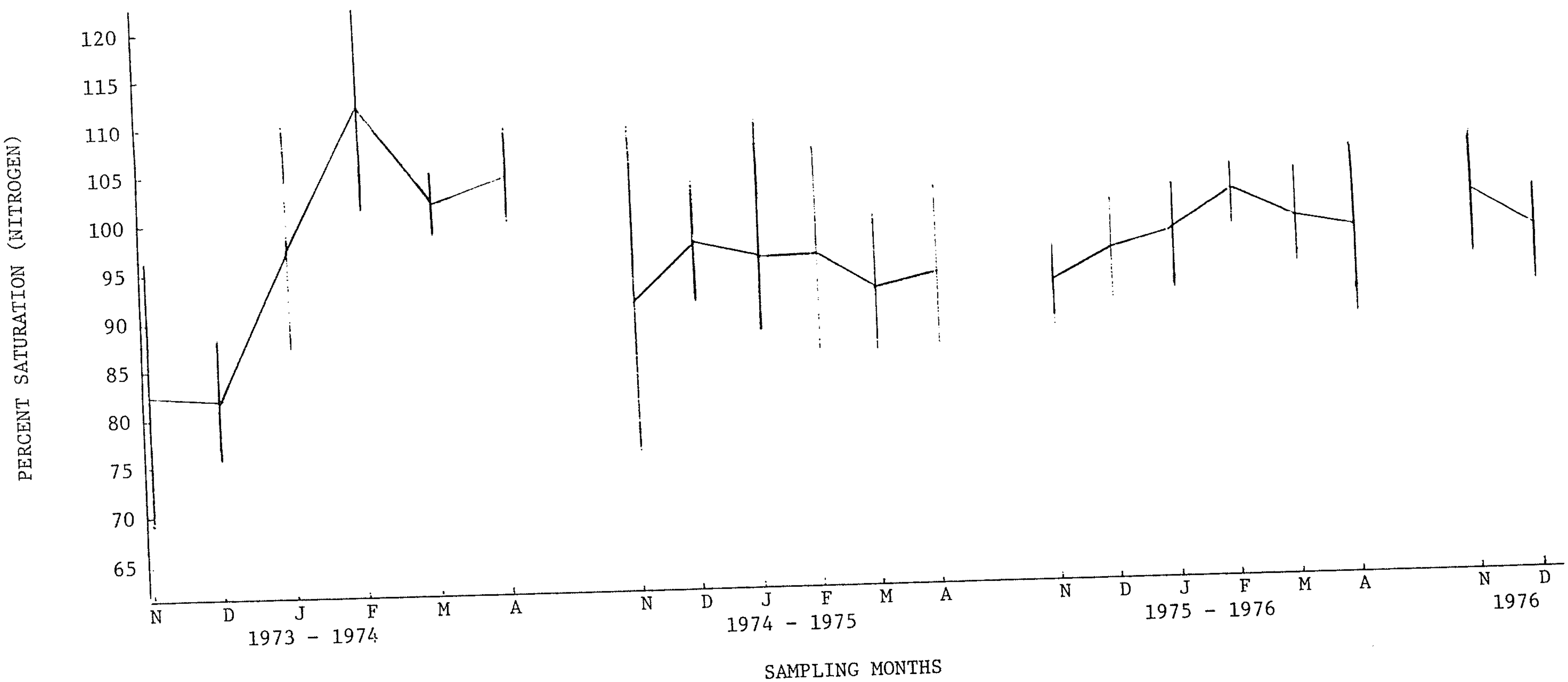

Figure 8-5. Mean and standard deviation of percent saturation values for nitrogen by sampling date, 1973 - 1976.